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OPERATIONS AND RESEARCH AT THE U.S. EPA INCINERATION RESEARCH FACILITY: ANNUAL REPORT FOR FY89

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16. ABSTRACT

The Environmental Protection Agency's Incineration Research Facility in Jefferson, Arkansas, is an experimental facility which houses two pilot-scale incinerators and the associated waste handling emission control, process control, and safety equipment, as well as onsite laboratory facilities.

During Fiscal Year 1989, a major facility expansion and reconfiguration construction effort was completed. Upon completion of the construction, incineration testing at the Facility was resumed. Hazardous waste incinerator trace metal emission regulation development for the Office of Solid Waste and a Superfund site remediation treatability study for Region I and the Office of Emergency and Remedial Response were major program support activities in Fiscal Year 1989.

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FOREWORD

Today's rapidly developing and changing technologies and industrial products and practices frequently carry with them the increased generation of materials that, if improperly dealt with, can threaten both public health and the environment. The U.S. Environmental Protection Agency is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. These laws direct the EPA to perform research to define our environmental problems, measure the impacts, and search for solutions.

The Risk Reduction Engineering Laboratory is responsible for planning, implementing, and managing research, development, and demonstration programs to provide an authoritative, defensible engineering basis in support of the policies, programs, and regulations of the EPA with respect to drinking water, wastewater, pesticides, toxic substances, solid and hazardous wastes, and Superfund-related activities. This publication is one of the products of that research and provides a vital communication link between the researcher and the user community.

This document reviews the accomplishments at the Incineration Research Facility (IRF) in Jefferson, Arkansas, during Fiscal Year 1989. In that twelve-month period, a major facility expansion and reconfiguration was completed. Upon completion of the construction, incineration research and testing at the Facility was resumed. Data for hazardous waste incinerator regulation development for the Office of Solid Waste and a Superfund site remediation treatability study for Region I and the Office of Emergency and Remedial Response were the major activities in Fiscal Year 1989.

E. Timothy Oppelt, Director
Risk Reduction Engineering Laboratory

ABSTRACT

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SECTION 1

INTRODUCTION

The U.S. Environmental Protection Agency's (EPA) Incineration Research Facility (IRF) in Jefferson, Arkansas, is an experimental facility which currently houses two pilot-scale incinerators (a rotary kiln incineration system and a liquid injection incineration system) and their associated waste handling, emission control, process control, and safety equipment. The IRF also has onsite laboratory facilities for waste characterization and analysis of process performance samples.

The objectives of research projects conducted at the IRF have been and continue to be as follows:

- To develop technical information on the performance capability of the hazardous waste incineration process to assist EPA Regional Offices and state environmental agencies in the review, assessment, and issuance of reasonable and responsible permits for regulated hazardous waste incineration facilities, and to assist waste generators and incinerator operators in the preparation of permit applications
- To develop incinerator system performance data for regulated hazardous wastes to support current Resource Conservation and Recovery Act (RCRA) incinerator regulations and performance standards, and to provide a sound technical basis for any necessary future standards
- To promote an understanding of the hazardous waste incineration process and develop methods to predict the performance of incinerators of varying scale and design for the major classes of incinerable hazardous wastes as a function of key process operating variables. These methods would also help to simplify and perhaps reduce the cost of permit and compliance testing.
- To develop methods of improving reliability and control of the incineration process, including the use of destruction and removal efficiency (DRE) surrogates
- To provide a means of conducting specialized test burns (particularly for high hazard or special waste materials so as Superfund site wastes) in support of specific Regional Office permitting or enforcement actions and Regional Office or private party Superfund site remediation efforts
- To test the performance of new or advanced incinerator components or subsystems, or emission control devices

During much of fiscal year 1989 (FY89, October 1, 1988, to September 30, 1989), testing activities were on hold while a major facility expansion and reconfiguration construction effort was completed. This construction effort included:

- Constructing a building encompassing the existing 3,100-ft^2 building to specifically provide containment areas for blowdown storage tanks and expanded drummed hazardous waste storage, storage areas for facility equipment not in use, and additional workspace area such that the new plus existing building enclosed area is brought to 15,200 ft^2

- Relocating the rotary kiln incineration system (RKS) completely inside the existing building and installing the ionizing wet scrubber, originally installed with the liquid injection incineration system (LIS), so that it could be used with the RKS

- Installing a new carbon bed/HEPA filter secondary air pollution control system, located within the existing 3,100-ft^2 building, on the RKS

These efforts were largely completed by July 1989.

Upon completion of most of the major facility construction efforts, testing activities at the facility resumed. In the final 10 weeks of FY89, incineration test activities were underway for 6 weeks. Fifteen shakedown or incineration tests of nominally 4- to 8-hour duration were performed. On an annual basis this level of testing productivity was down from that experienced during FY87 and FY88.[1,2] However, when the fact that the facility was only available for testing for 10 weeks of the FY is considered, the level of testing productivity achieved during the available time period in FY89 compares favorably to the level of productivity achieved during the preceding two FYs.

Two major EPA Program/Regional Office programs were supported through test activities in FY89.

- The hazardous waste incinerator trace metal emission regulation development program within the Office of Solid Waste (OSW) via testing of the fate of several trace metals fed to the RKS with an ionizing wet scrubber (IWS) for particulate and acid gas control

- The Superfund site remediation program within the Office of Emergency and Remedial Response (OERR) as administered by EPA Region I via treatability testing of contaminated soil from the Baird and McGuire Superfund site in Massachusetts

In addition, the results of a companion series of trace metal fate tests in the RKS with a venturi scrubber/packed column scrubber for particulate and acid gas control, completed at the end of FY88, were assembled and reported in FY89.

Activities completed during FY89 are discussed in more detail in the following sections. Section 2 describes the facility construction, reconfiguration, and upgrade efforts completed; Section 3 discusses the results of the trace metal, venturi/packed column scrubber tests reported in FY89; Section 4 outlines the trace metal/IWS tests completed in July/August 1989; and Section 5 describes the Region I Superfund soil treatability tests completed in September 1989.

During FY89 a new initiative to identify and respond to potential third party users of the IRF was begun. The Federal Technology Transfer Act specifically allows for the use of Government facilities and equipment in joint projects with private sector concerns. In response, the IRF operations and research contract was modified in FY89 to allow this type of usage. Several third party inquiries were pursued during the year; three advanced to the proposal stage. These are discussed in Section 6.

Finally, Section 7 discusses external communication activities associated with the facility and its operation. Section 8 closes with an outline of plans for activities to be completed in FY90.

SECTION 2

FACILITY UPGRADE CONSTRUCTION AND INCINERATION SYSTEM RECONFIGURATION

When the IRF was conceived, its primary use was expected to be performance of pilot-scale incineration research using synthetic hazardous waste mixtures (soups). The facility was constructed with that objective in mind. Thus, there was minimal provision for hazardous waste or hazardous waste incineration residuals storage, and the onsite building facilities were appropriate for an onsite staff of 14 doing incineration research at a moderate pace.

During FY86, the pace of testing efforts was accelerated significantly, and the staff size increased appropriately.[3] Continued acceleration of testing efforts and increases in onsite staff size continued into FY87 and FY88 so that by FY88 the onsite staff had grown to 19 full-time individuals. The test schedule completed in FY87 and FY88 encompassed 25 to 26 weeks of testing (periods of incinerator system operation).[1,2] Most of this testing was performed while firing listed hazardous wastes. This increase in pace of test effort, operating staff size, and frequency of actual hazardous waste testing exceeded the realistic capabilities of the physical plant at the facility. Thus, it was decided early in 1987 to plan and initiate several facility expansion efforts to bring the physical plant to a form which could handle the increased test demands and substantially increased incidence of actual hazardous waste testing.

Initial facility expansion planning was completed in FY87. The conceptual design for the upgraded facility was completed in January 1988 by the architect contracted to perform this effort. The detailed design and contractor bid specification package was completed in April 1988. A bid solicitation from the National Center for Toxicological Research (NCTR), the host facility for the IRF, was issued in July 1988. The contract to perform the construction was awarded in September.

Construction was initiated in October 1988, the beginning of FY89. The original construction contract completion was scheduled for the second quarter of FY89. However, owing to an unusually high frequency of inclement weather during the fall and early winter of 1988/89, it became clear that the construction schedule would slip into the third and perhaps early fourth quarter of FY89. It was then decided to embark upon a reconfiguration of the incineration systems at the facility so that one complete system could be located entirely within the original facility building. This action would allow testing activity to resume relatively independently of the new building completion schedule.

The new building construction and facility expansion efforts are discussed in Section 2.1. Section 2.2 outlines the incineration system reconfiguration efforts completed.

2.1 FACILITY UPGRADE CONSTRUCTION

The specific physical plant modifications and additions which were implemented in FY89 included:

- Upgrading the former outside air pollution control system area to approved RCRA containment area status
- Adding liquid waste storage tank containment area
- Adding substantially increased containerized waste storage area
- Adding waste processing and general work areas
- Erecting a steel-walled building over all added containment and work areas, including the existing incinerator building
- Constructing a new visitor paved parking area and providing nearby utilities for relocated office space

Figure 1 is a plan view of the new building showing the additional enclosed containment and work areas. The existing building, which was enclosed within the new building, is also shown in the figure. As indicated, the total building area under roof has been expanded from the former 3,100 ft^2 to 15,200 ft^2.

As noted in the introductory paragraphs to Section 2, the contract to perform the building construction was awarded in September 1988. A contract start date of October 17 was specified. During the first two weeks of FY89, the IRF staff dismantled all equipment placed outside the former building to allow the contractor free access to all outside areas. This effort included:

- Relocating various office and storage trailers to locations which would not interfere with construction activities
- Relocating the temporary scrubber blowdown storage tanks
- Dismantling the RKS air and fuel supply measurement and control valving system (gas train)
- Dismantling all outside air pollution control system (APCS) equipment
- Removing the RKS dump stack
- Installing the RKS heat exchanger system coolant/air heat exchanger and surge tank on the pad previously prepared for them

In addition, all instrumentation in the instrument laboratory in the former building was relocated to new space made available by NCTR so that this equipment could remain accessible and operational during construction.

Building construction activities were initiated on schedule with site grading completed by the end of October. Concrete building foundation footings and grade beams were installed

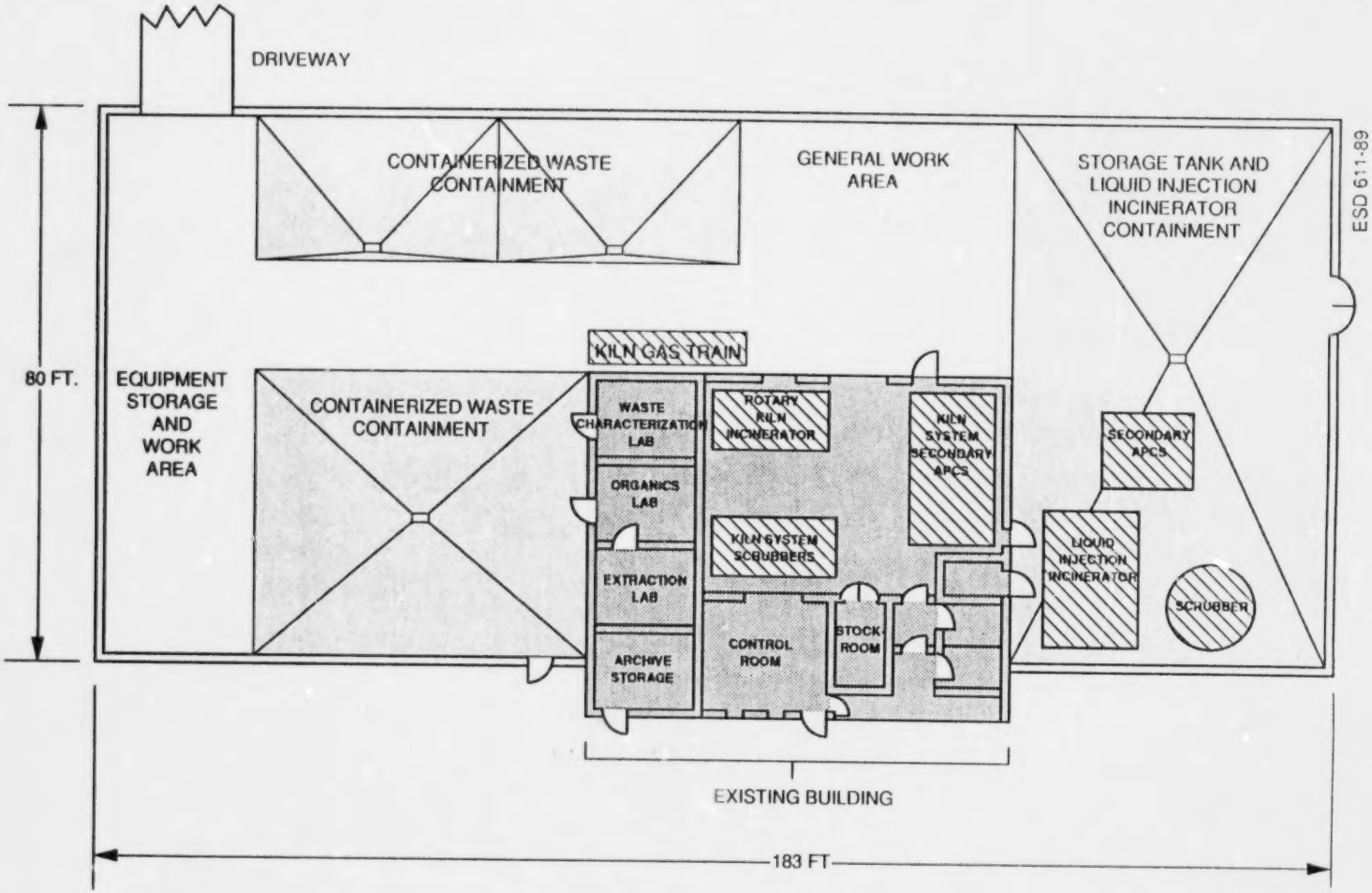


Figure 1. Upgraded incineration research facility plan view.

during November and into December. However, unusually high precipitation during December prevented completion of the concrete floor slabs. High precipitation continued through the winter, resulting in increasing construction delays. The concrete floor slabs were not completed until March 1989. The metal building frame was erected by the end of April. The metal shell with roof was completed in May. Final completion of the building, with the exception of a few remaining details, occurred in August, compared to an original schedule of March.

Since the expansion completed in FY89 represents a major modification to the facility, modification of its hazardous waste management permit is required. This modification is specifically required before the additional waste management units (the tank storage area and the additional containerized waste storage area) are put into operation. Accordingly, an application for a major modification to the facility's permit was submitted to the Arkansas Department of Pollution Control and Ecology (ADPCE) on August 29, 1988. A notice of deficiencies (NOD) was received from ADPCE on December 29. A revised application was submitted on January 25, 1989. The current review schedule provides for issuing a draft permit modification for public comment by early 1990.

2.2 INCINERATION SYSTEM RECONFIGURATION

In the configuration that existed prior to starting construction of the expanded facility, the two IRF incineration systems (the RKS and the LIS) were located inside the existing IRF building.[2] The primary APCS for the RKS, consisting of a venturi scrubber/packed column scrubber combination, was also located inside the building. However, the primary APCS for the LIS, comprised of a packed column scrubber and an ionizing wet scrubber (IWS), and the secondary APCS, consisting of a carbon bed absorber and a HEPA filter, were located outside the building. All this outside equipment was dismantled in preparation for the new building construction. This resulted in the inability to operate either incineration system during the major portion of the new building construction period.

Original construction plans were to complete the new building concrete floor as quickly as possible, at the latest by mid-January 1989. With the concrete floor completed, the IRF staff could reassemble the APCS systems in their former locations (although now on concrete) and reestablish the capability to perform incineration testing. However, it became clear in November 1988 that new building construction efforts were likely to fall behind schedule. In addition, the initial series of tests planned for FY89 testing required installing the IWS system, formerly with the LIS, so that it could be used with the RKS.

Recognizing that construction efforts were likely to continue to fall behind schedule, and that some amount of equipment reconfiguration associated with the RKS would be required in any event, it was decided to assemble a complete RKS with IWS and secondary APCS within the existing building. This would allow testing in the RKS to proceed relatively independently of the construction contractor's schedule. This effort required:

- Removing the LIS from the existing building
- Relocating the IWS in the existing building and connecting it to the RKS
- Relocating the ID fan in the existing building

- Installing new RKS burners with a burner fuel and air supply flow measurement and control valve system

- Installing a new secondary APCS in the existing building

- Reconfiguring and installing required new flue gas ductwork and stack, scrubber system plumbing, and process control system wiring

A new burner with air and fuel control system (gas train) was required since the system in place at the start of construction was owned by the existing burner system vendor, American Combustion, Inc. It had been installed on the RKS specifically for use in the Superfund Innovative Technology Evaluation (SITE) test program completed in FY88.[2] This system was returned to American Combustion. It was decided by joint EPA/IRF staff discussion not to replace the originally installed RKS burner system (replaced by the American Combustion system for the SITE program) because the original system was not sufficiently flexible.

It was also decided to install a completely new secondary APCS because the original APCS had presented problems in past system operation, and its carbon packing had reached the end of its useful life.

The LIS was removed from the building in November 1988. Reconfigured system design efforts proceeded during December 1988 and January 1989, and equipment procurement was completed in February. Equipment installation and system fabrication efforts proceeded from March through June. New system startup occurred in early July, and shakedown was completed by mid-July. The new system was placed into test operation in late July.

SECTION 3

TRACE METAL EMISSION AND DISCHARGE TESTING IN THE ROTARY KILN SYSTEM WITH THE VENTURI SCRUBBER/PACKED COLUMN SCRUBBER AIR POLLUTION CONTROL SYSTEM

The RCRA hazardous waste incinerator performance standards promulgated by EPA in January 1981 established particulate and HCl emission limits and mandated 99.99 percent destruction and removal efficiency (DRE) for principal organic hazardous constituents (POHCs). However, subsequent risk assessments have suggested that, of the total risk to human health and the environment from otherwise properly operated incinerators, hazardous constituent trace metal emissions may pose the largest component. Currently, the data base on trace metal emissions from incinerators available to support regulations is very sparse.

In response to these data needs, an extensive series of tests was conducted at the IRF to support OSW (R. Holloway, S. Garg, coordinators) in the investigation of the fate of trace metals fed to a rotary kiln incinerator equipped with a venturi scrubber/packed column scrubber for particulate and acid gas control.

A primary objective of the tests was to investigate the fate of five hazardous constituent trace metals fed in a synthetic solid waste matrix, as a function of incinerator operating temperatures and feed chlorine content. These five metals were arsenic, barium, cadmium, chromium, and lead (As, Ba, Cd, Cr, and Pb, respectively).

In addition, as part of the Risk Reduction Engineering Laboratory (RREL) program to support trace metal emission regulation development, a separate OSW-sponsored effort by another EPA contractor (C. C. Lee, coordinator) is developing a numerical model to aid in predicting the relative distribution of trace metals in incinerator discharges. Thus, a second objective was to supply data to evaluate the predictive capabilities of this model and to perhaps guide further model refinement. To support this objective, the tests also included four nonhazardous constituent trace metals, namely, bismuth, copper, magnesium, and strontium (Bi, Cu, Mg, and Sr).

Finally, in the absence of information on the predominant valence state of chromium in incinerator discharges, risk assessments have generally assumed that the entire discharge is in the more toxic hexavalent form. This assumption has resulted in specifying conservative chromium emission limits in the regulatory development process. Hence, another objective of this program was to develop data on the valence state of chromium discharges as a function of chlorine and chromium valence state in the feed.

The actual tests were completed at the end of FY88.[2] However, data reduction, interpretation, and reporting occurred in FY89. An outline of the test program and test results is given in the following subsections.

3.1 TEST PROGRAM

The test program consisted of both an eight-test parametric trace metals series (Tests 4 through 11) in which the test waste feed contained nine metals, and a three-test chromium valence state series (Tests 1, 2, and 3) in which the feed contained either Cr(+3) or Cr(+6). All tests were performed in the rotary kiln incinerator system (RKS) at the IRF.

Figure 2 gives a simplified schematic of the RKS configuration used for these tests, and Table 1 summarizes its design characteristics. The system consists of a rotary kiln chamber, a transition section, and a fired afterburner chamber. The primary air pollution control system (APCS) for these tests consisted of a quench section, a venturi scrubber, and a packed column scrubber. In addition, the originally installed air pollution control system, consisting of a carbon-bed adsorber and a HEPA filter, was in place to ensure that organic compound and particulate emissions were negligible during less-than-optimal test conditions.

3.1.1 Synthetic Test Mixture

The synthetic waste fired during the test program was composed of a clay absorbent containing 30 percent (weight) organic liquids. Trace metals, in aqueous solution form, were metered onto the solid, which was fed to the rotary kiln via a screw feeder.

Table 2 lists the metal concentrations of the synthetic feed waste for each test. Chromium inherently present in the clay contributed about 50 percent of the actual feed chromium. Magnesium in the clay accounted for virtually all of the actual feed magnesium.

The organic liquid, a mixture of toluene and varying amounts of tetrachloroethylene and chlorobenzene, supplied the heat content and POHC. It also introduced chlorine at levels ranging from zero to nominally 8 percent by weight. The analyzed fractions of these organics are listed in Table 3.

3.1.2 Test Conditions

For all tests, the clay/organic liquid was fed at about 63 kg/hr (140 lb/hr). The aqueous metal solution was injected at 1 L/hr. Estimated solids residence time in the kiln was 1 hour. The test variables for the parametric tests were feed chlorine content (0, 4, and 8 percent), kiln temperature (816°, 871°, and 927°C), and afterburner temperature (982°, 1093°, and 1204°C). The three levels for these variables constituted a factorial experimental matrix.

For the three chromium valence state tests, waste-feed chromium valence state and chlorine contents were varied. Two tests had trivalent chromium feed. One of these had no chlorine while the other had nominally 8-percent chlorine in the feed. The third test had hexavalent chromium and no chlorine in the feed. Incinerator operating conditions during these tests were held constant: kiln temperature at about 870°C, afterburner temperature at about 1093°C.

For all tests, excess air was targeted at 11.5- and 7.5-percent oxygen in the kiln and the afterburner exit flue gas, respectively. These were successfully maintained within ±1.5 percent for all tests. Figure 3 illustrates the actual and target incinerator temperatures. For all tests, the primary air pollution control system operated at design conditions, with venturi pressure drop at 5.0 to 6.2 kPa (20 to 25 inches W.C.) and scrubber pH averaging 7.1.

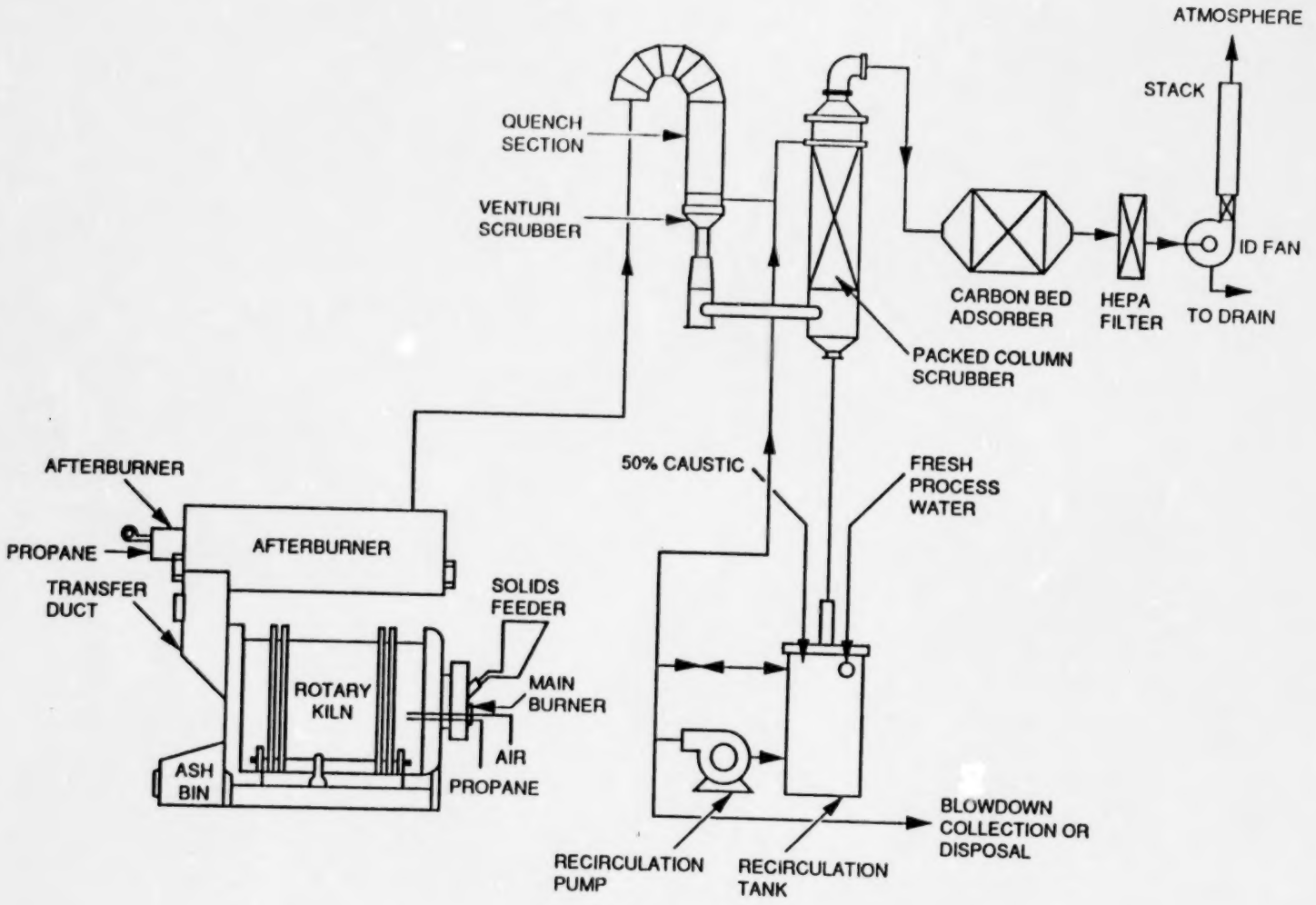


Figure 2. **Schematic of the IRF rotary kiln system for the venturi/packed column scrubber trace metal tests.**

TABLE 1. DESIGN CHARACTERISTICS OF THE IRF ROTARY KILN SYSTEM FOR THE VENTURI/PACKED COLUMN SCRUBBER TRACE METAL TESTS

Characteristics of the Kiln Main Chamber

Length, outside	2.61 m (8 ft 7 in)
Diameter, outside	1.22 m (4 ft)
Length, inside	2.44 m (8 ft)
Diameter, inside	0.95 m (3 ft 1-1/2 in)
Chamber volume	1.74 m^3 (61.4 ft^3)
Construction	0.63 cm (0.25 in) thick cold rolled steel
Refractory	12.7 cm (5 in) thick high alumina castable refractory, variable depth to produce a frustroconical effect for moving solids
Rotation	Clockwise or counterclockwise 0.2 to 1.5 rpm
Solids retention time	1 hr (at 0.2 rpm)
Burner	American Combustion Burner, rated at 880 kW (3.0 MMBtu/hr) with dynamic O_2 enhancement capability
Primary fuel	Propane
Feed system	
Liquids	Positive displacement pump via water-cooled lance
Sludges	Moyno pump via front face, water-cooled lance
Solids	Metered twin-auger screw feeder or fiber pack ram feeder
Temperature	1,010°C (1,850°F)

Characteristics of the Afterburner Chamber

Length, outside	3.05 m (10 ft)
Diameter, outside	1.22 m (4 ft)
Length, inside	2.74 m (9 ft)
Diameter, inside	0.91 m (3 ft)
Chamber volume	1.80 m^3 (63.6 ft^3)
Construction	0.63 cm (0.25 in) thick cold rolled steel
Refractory	15.24 cm (6 in) thick high alumina castable refractory
Gas residence time	1.2 to 2.5 sec, depending on temperature and excess air
Burner	American Combustion Burner rated at 440 kW (1.5 MMBtu/hr) with dynamic O_2 enhancement capability
Primary fuel	Propane
Temperature	1,200°C (2,200°F)

Characteristics of the Air Pollution Control System

System capacity	
Inlet gas flow	107 m^3/min (3773 acfm) at 1200°C (2200°F) and 101 kPa (14.7 psia)
Pressure drop	
Venturi scrubber	7.5 kPa (30 in WC)
Packed column	1.0 kPa (4 in WC)
Liquid flow	
Venturi scrubber	77.2 L/min (20.4 gpm) at 69 kPa (10 psig)
Packed column	116 L/min (30.6 gpm) at 69 kPa (10 psig)
pH control	Feedback control by NaOH solution addition

TABLE 2. INTEGRATED FEED METAL CONCENTRATIONS FOR THE PARAMETRIC TRACE METALS TEST SERIES

Metal	Indigenous (in clay)	Metal concentration (ppm)										
		Test 1 (9/29/89)	Test 2 (9/28/89)	Test 3 (9/26/89)	Test 4 (9/14/88)	Test 5 (8/25/88)	Test 6 (9/16/88)	Test 7 (8/30/88)	Test 8 (9/7/88)	Test 9 (9/9/88)	Test 10 (9/20/88)	Test 11 (9/22/88)
Arsenic					47	36	46	38	36	37	57	52
Barium					54	44	53	53	55	56	54	51
Beryllium	12				180	110	180	130	160	190	180	180
Cadmium					10	6	9	8	8	9	10	9
Chromium (total) (+6)	53	84 44	86 1.6	89 1.7	93	77	85	85	89	89	90	84
Copper					490	370	480	480	510	500	480	480
Lead	3				60	40	50	51	53	52	56	49
Magnesium	22,000				17,700	17,600	16,700	17,000	17,700	17,900	16,200	16,500
Strontium	34				330	200	270	250	270	290	330	290

TABLE 3. POHC CONCENTRATIONS IN CLAY/ORGANIC LIQUID FEED

Test	Test Date	Weight percent in mixture			
		Toluene	Tetrachloroethylene	Chlorobenzene	Chlorine content*
Mixture 1 Target Composition		28.6	0	0	0
Measured composition					
1	9/29/88	27.9	0	0	0
2	9/28/88	27.9	0	0	0
4	9/14/88	23.2	0	0	0
Mixture 2 Target Composition		21.7	3.4	3.4	4
Measured composition					
5	8/25/88	16.7	3.0	3.6	3.7
6	9/16/88	20.5	3.6	3.5	4.2
7	8/30/88	19.7	3.2	3.2	3.8
8	9/07/88	17.1	3.1	3.0	3.6
9	9/09/88	16.5	2.9	2.9	3.4
10	9/20/88	22.5	3.9	3.8	4.6
Mixture 3 Target Composition		14.9	6.9	6.9	8
Measured composition					
3	9/26/88	15.9	7.5	6.7	8.5
11	9/22/88	14.6	7.1	6.9	8.3

*Based on measured tetrachloroethylene and chlorobenzene concentrations.

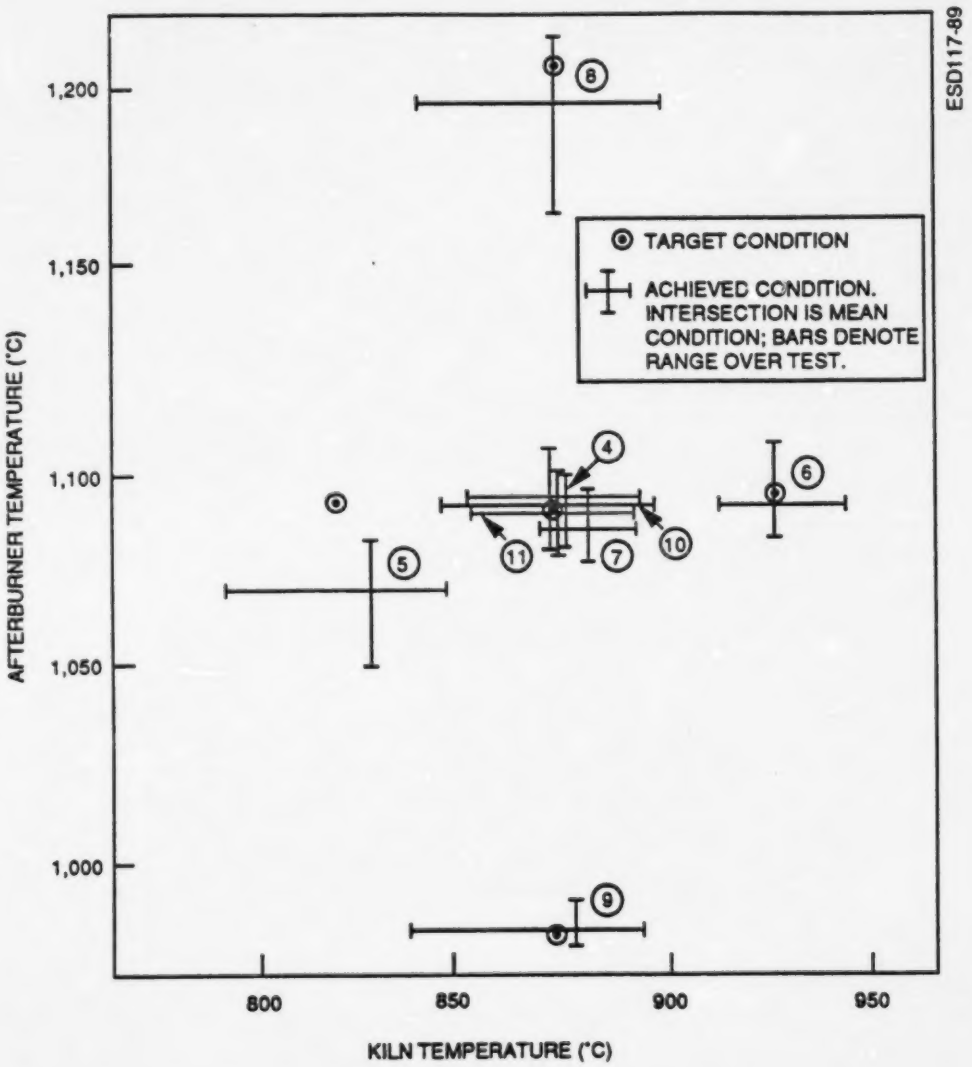


Figure 3. Actual versus target operating temperatures for parametric trace metal tests.

3.1.3 Sampling and Analysis

Figure 4 identifies the sampling locations for the tests. Continuous emission monitors (CEMs) were arranged to monitor O_2, CO, CO_2, NO_x, and total unburned hydrocarbon (TUHC) concentrations at the kiln exit, the afterburner exit, the scrubber exit, and the stack. Other samples collected were feed, scrubber blowdown water, kiln ash, and flue gas at the afterburner and scrubber exits. Samples were also collected at the stack for evaluating hazardous waste management permit compliance. Since the target analytes differed for the two test series, the sampling and analysis matrix was tailored specifically for each series.

For the parametric trace metal tests, composite feed samples were subjected to ultimate, volatile organic, and trace metal analyses. Virgin clay samples were subjected to trace metal analyses to determine background metal concentrations. Composite kiln ash samples were collected and subjected to metal analysis.

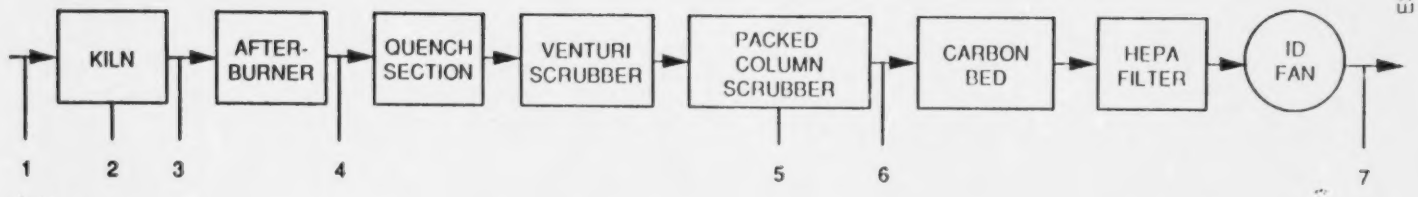
Flue gas sampling at the afterburner exit consisted of volatile organic sampling train (VOST) sampling and a variation of a Reference Method 17 train which allowed collection of large particulate mass, HCl, and any trace metals not collected in the particulate. At the scrubber exit, a VOST and a Method 5 train modified for trace metal capture collected samples for volatile organic and metal analyses, respectively. At the stack, a Method 5 train sampled for HCl and particulate for permit compliance.

The sampling trains for metals capture (the variations of the Method 17 and Method 5 trains noted above) included impingers charged with a 5 percent nitric acid/10 percent hydrogen peroxide solution. These impingers were included to ensure that any metal not collected with the particulate (i.e., metal in the vapor phase at the particulate collection temperature or metal dissolved in moisture carryover from the particulate collection section of the sampling train) would be captured in the impinger.

For the chromium-valence tests, composite feed samples were subjected to ultimate, volatile organic, and total chromium analyses. Composite grab samples of chromium spike solution, scrubber blowdown, and kiln ash were collected during each test for total chromium and Cr(+6) analyses.

Flue-gas sampling employed two variations of a Method 5 train. At the afterburner exit, one train with impingers containing 0.1N NaOH followed by HNO_3/H_2O_2 sampled for particulate load and total chromium. Simultaneously, a second train with the filter removed sampled for Cr(+6) and, during test 3, HCl. Impingers in this train contained 0.1N NaOH, which was believed better able to preserve Cr(+6). A similar arrangement was duplicated at the scrubber exit.

The VOST samples were subjected to purge and trap GC/FID for organic analysis. The grab composite samples of feed, ash, scrubber liquor, and the Method 5 and Method 17 train samples were subjected to inductively coupled argon plasma (ICAP) spectroscopy or atomic absorption (AA) spectroscopy methods for metal analysis.



SAMPLE LOCATIONS

	Feeds and Residuals				Continuous Monitors					Flue Gas					
Sampling Point	Clay Organic Liquid	Metal Spike Solution	Kiln Ash	Scrubber Blowdown	O_2	CO, CO_2	NO_x	Unheated TUHC	Heated TUHC	Method 5 (Tests 1-3) with multiple metals impingers, (particulate and Cr)	Simultaneous Method 5 (Tests 1-3) with no filter and caustic impingers (Cr(+6) and HCl)	Method 17 (Tests 4-11) with multiple metals impingers (particulate, metals and HCl)	Method 5 (Tests 4-11) with multiple metals impingers (particulate, metals, and HCl)	VOST (volatile organics)	Method 5 (particulate and HCl)
1	X	X													
2			X												
3					X										
4					X	X		X		X	X	X		X[a]	
5				X											
6						X	X	X	X	X	X		X	X[b]	
7					X	X			X					X[a]	X

[a]Tests 4 through 11 only.
[b]Tests 5, 8, and 11 only.

Figure 4. Sampling summary for the chromium valence state and parametric trace metals test series.

3.2 TEST RESULTS

3.2.1 Trace Metal Discharge Distributions

When subjected to incineration conditions, the metals are expected to vaporize to varying degrees, depending on their volatilities. Figure 5 shows the amounts of metal found in each discharge stream, normalized to the total found in the three discharge streams, namely, kiln ash, scrubber exit flue gas, and scrubber liquor. In Figure 5, the bar for each metal represents the range in the fraction accounted for by each discharge stream over all eight parametric tests, with the average fraction from all tests noted by the midrange tic mark. Metal discharge distribution data in Figure 5 is plotted versus the metal's volatility temperature. A metal's volatility temperature is the temperature at which a principal vapor species of the metal has a vapor pressure of 10^{-6} atm. Figure 5 shows that the more volatile metals, i.e., those having lower volatility temperatures (Cd, Bi, and Pb), tend to be less prevalent in the kiln ash. The more refractory metals, i.e., those with higher volatility temperatures (Ba, Cu, Sr, Cr, and Mg) tend to be found predominantly in the kiln ash. This observation is consistent with expectation.

The notable exception, arsenic, exhibited unexpected refractory behavior and remained predominantly in the kiln ash. Arsenic's plotted volatility temperature is that for As_2O_3. The fact that arsenic was observed to be significantly less volatile than expected, based on the As_2O_3 volatility temperature, suggests that As_2O_3 was not a predominant arsenic species in the incinerator and that some other, less volatile species (perhaps an arsenate) was the favored arsenic compound. An alternative explanation is that strong chemical interaction occurred between arsenic and the clay feed matrix.

It is interesting to note the sharp break in observed volatility between lead and bismuth (average kiln ash fractions of 20 to 32 percent) and barium (average kiln ash fraction of 77 percent). Six of the eight parametric tests were performed with kiln temperature of 870°C, one at 825°C, and one at 930°C. These temperatures are right in the range of the volatility temperature change from 621°C (Bi) and 627°C (Pb) to 849°C (Ba).

3.2.2 Metal Distributions in Scrubber System

The above observations suggest that substantial portions of the volatile metals escaped the incinerator. For effective control, these need to be captured by the venturi and packed column scrubber system. Figure 6 shows that this may not be the case. The apparent scrubber collection efficiency averaged only 36 to 45 percent for the volatile metals (Cd, Bi, and Pb). Collection efficiencies for the most refractory metals (Sr, Mg, and Cr) averaged greater than 65 percent. This behavior is consistent with expectation. Most metal vaporized at some point in the incinerator will ultimately condense when the flue gas is cooled to its scrubber exit temperature of about 75°C. Condensation occurs via fume formation, or condensation onto available flue gas particulate. Fume formation results in very fine particulate. Condensation onto available particulate results in concentrating the metal in fine particulate, since condensation is a per unit of surface area event, and the surface-area-to-mass ratio is increased in fine particulate. Both mechanisms tend to concentrate volatilized metal in fine particulate. Since venturi scrubbers collect coarse particulate at greater efficiency than fine particulate, a poorer efficiency in collecting volatile metals is expected.

This same mechanism may explain the poor observed collection efficiency for arsenic and, perhaps, copper. The above discussion noted that arsenic was observed to be relatively refractory based on its high kiln ash fraction. However, any amount carried in entrained flyash

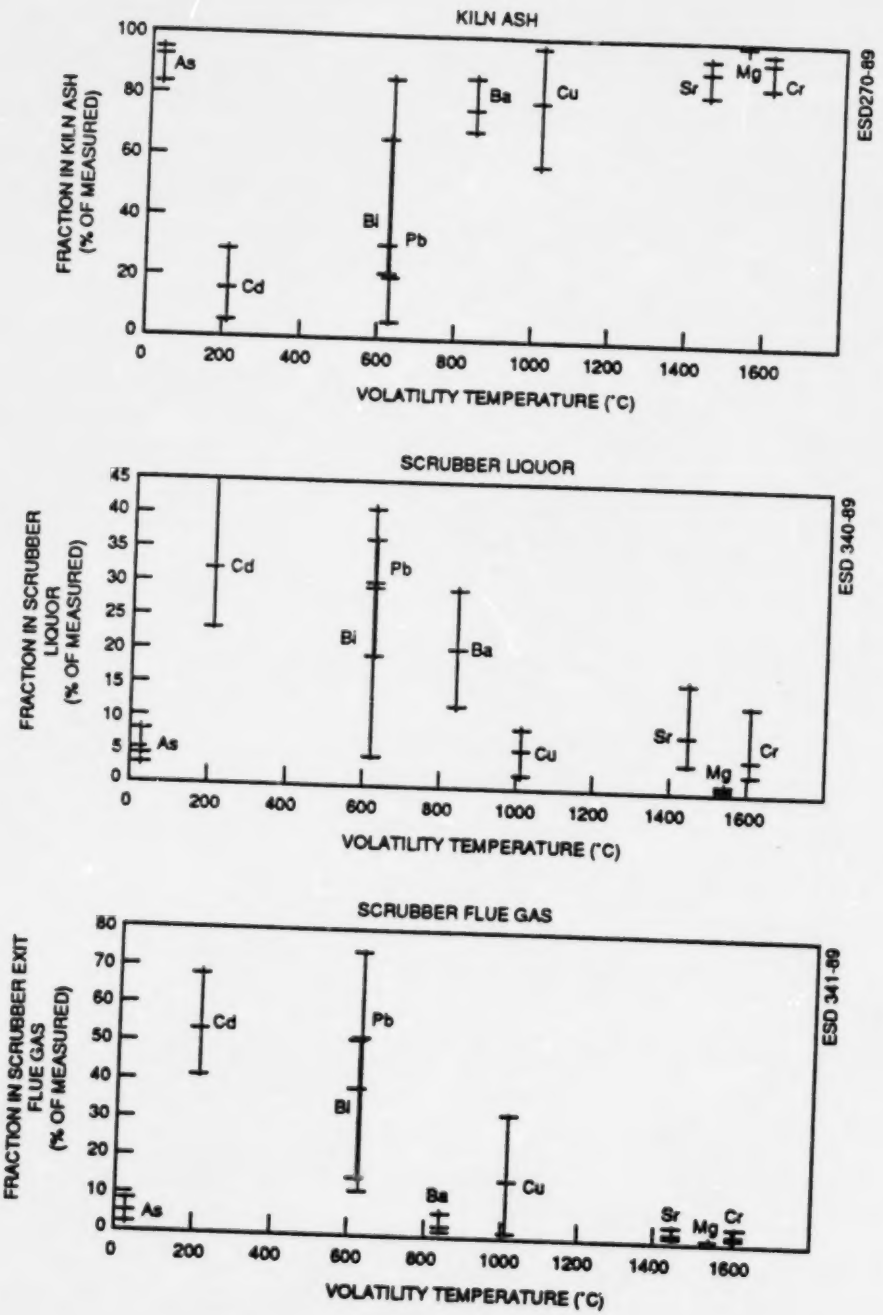


Figure 5. Distribution of metals in discharge streams.

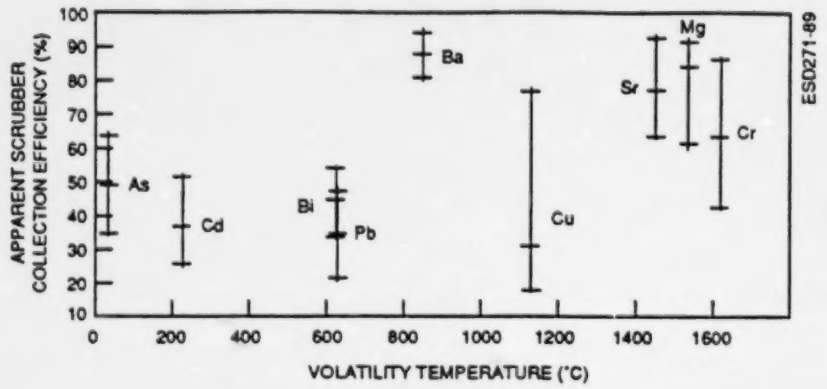


Figure 6. Apparent venturi/packed column scrubber efficiencies for trace metals.

out of the kiln and into the afterburner would experience the higher afterburner temperature (980° to 1200°C in tests performed). Thus, further opportunity to volatilize in the afterburner exists. If the predominant arsenic species had a volatility temperature above test kiln temperature (825° to 930°C) but below afterburner temperature, then volatization in the afterburner may have occurred, leading to the poor scrubber collection efficiency for the small amount of arsenic carried into the afterburner. Similarly, entrained copper (volatility temperatures of 1116°C) may have volatilized in the afterburner, leading to its poor observed scrubber collection efficiency. If this were the case, the good collection efficiencies for barium could remain unexplained, however.

3.2.3 Effect of Incinerator Operating Conditions

Kiln temperature within the tested range had a minor effect on the discharge distributions of arsenic, cadmium, and lead. Of the three metals, the effect was most pronounced, though still minor, for cadmium, shown in Figure 7.

Afterburner temperature within the tested range had little to no effect on discharge distributions of the nonvolatile metals. Increasing afterburner temperature caused a slightly increased fraction of the three volatile metals (cadmium, lead, and bismuth) in the flue gas and a corresponding decreased fraction in the scrubber liquor. The most pronounced effect was for lead, shown in Figure 8.

Varying the chlorine in the waste had little to no effect on the distribution of arsenic, barium, chromium, strontium, or magnesium. However, the increase in volatility for the volatile metals, cadmium, bismuth, and lead, in addition to that for copper, was substantial. The most pronounced effect was for lead, as shown in Figure 8. This observation is consistent with expectation, since metal chlorides (possible with chlorine in the feed) are typically more volatile than the base metal or metal oxides. This is especially the case for lead. With no chlorine present, lead metal is the most volatile lead species, with a volatility temperature of 627°C. With chlorine present, the formation of the significantly more volatile $PbCl_4$, with a volatility temperature of -15°C, is possible.

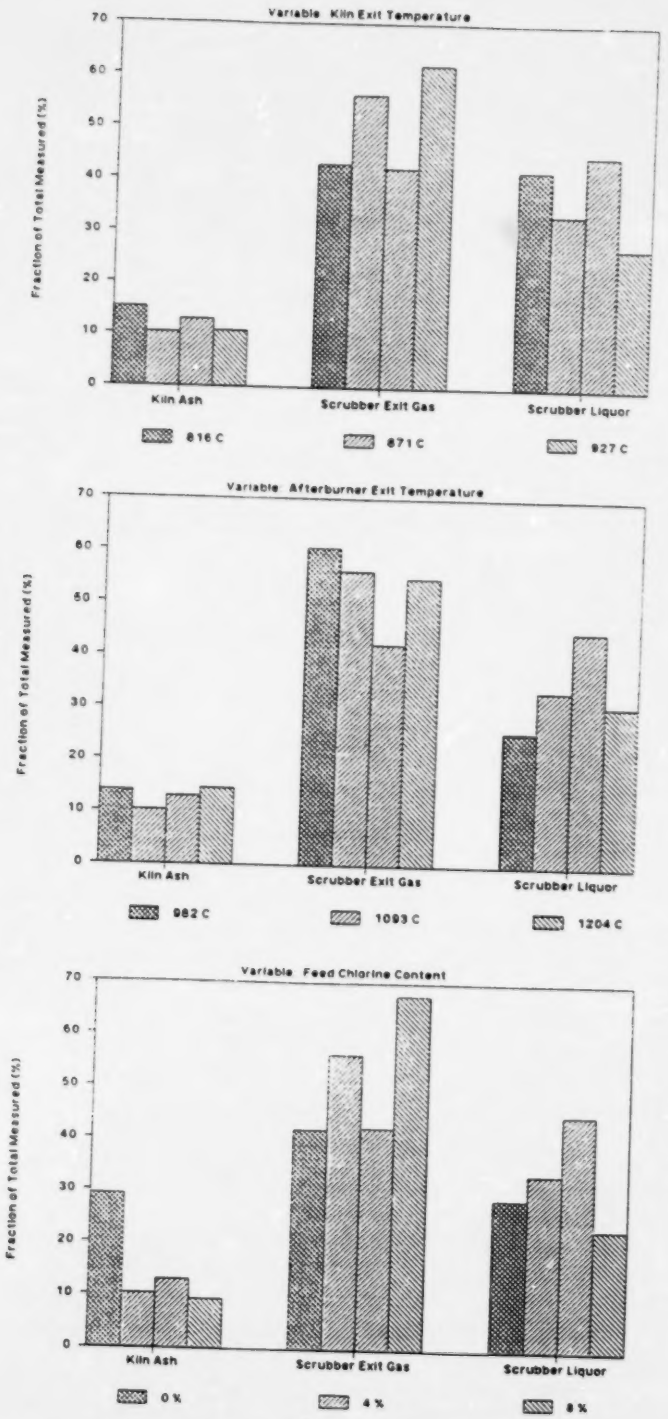


Figure 7. Cadmium discharge distributions for the parametric trace metal tests.

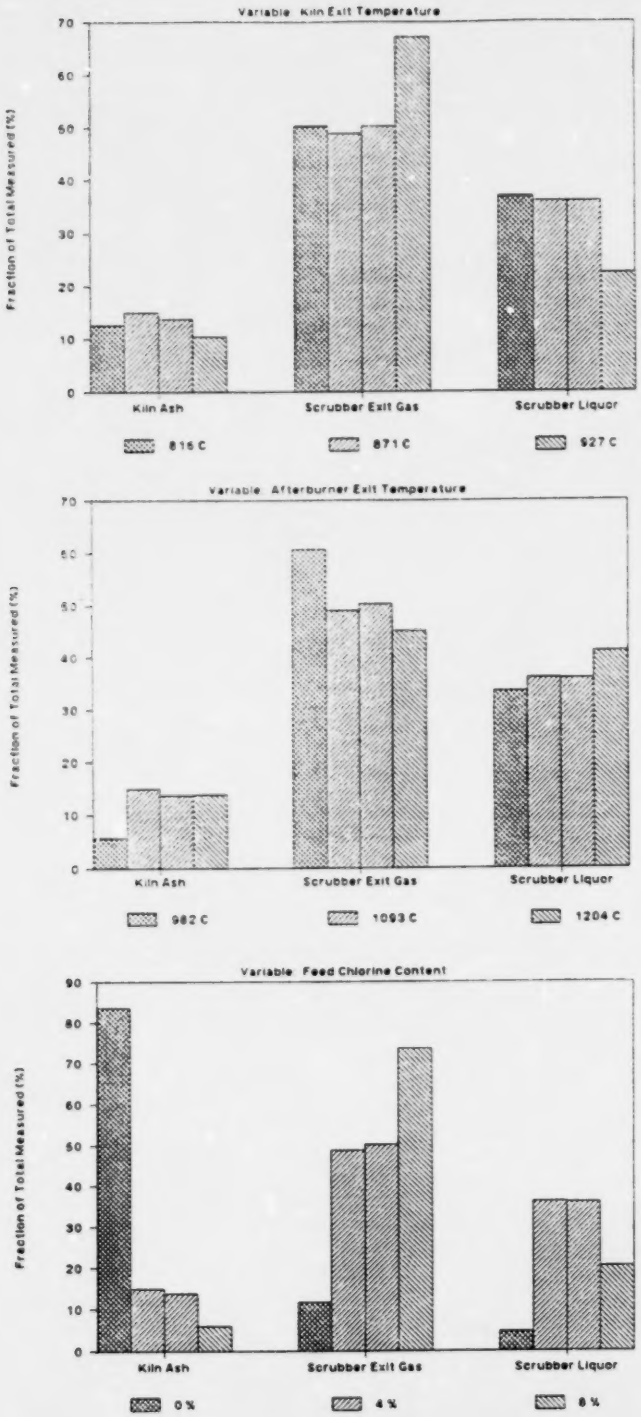


Figure 8. Lead discharge distributions for the parametric trace metal tests.

3.2.4 Particle Size Distribution

Figure 9 shows that the afterburner exit particle size distributions for all tests were roughly log normal. The absence of chlorine in the waste appears to shift the particles to a larger size distribution. This is consistent with the expectation that the presence of chlorine increases the volatility of the feed inorganic constituents. In such a case, condensation of volatilized inorganic compounds would tend to produce finer particles.

3.2.5 Metal Particle Size Distribution

Trace metal contents in four size fractions in afterburner exit particulate (nominally <2, 2 to 4, 4 to 10, and >10 μm) were analyzed. Figure 10(a) shows the average fractions of arsenic, barium, cadmium, chromium, and lead that were distributed over the four size ranges. Similar results for the four nonhazardous constituent metals, bismuth, copper, magnesium, and strontium, are shown in Figure 10(b).

It appears that the more volatile metals, bismuth and barium, tend to concentrate on the finer particles. The relatively nonvolatile metals, chromium, copper, magnesium, and strontium, tend to concentrate on the larger particles. This observation is consistent with the volatilization/condensation mechanism discussed previously.

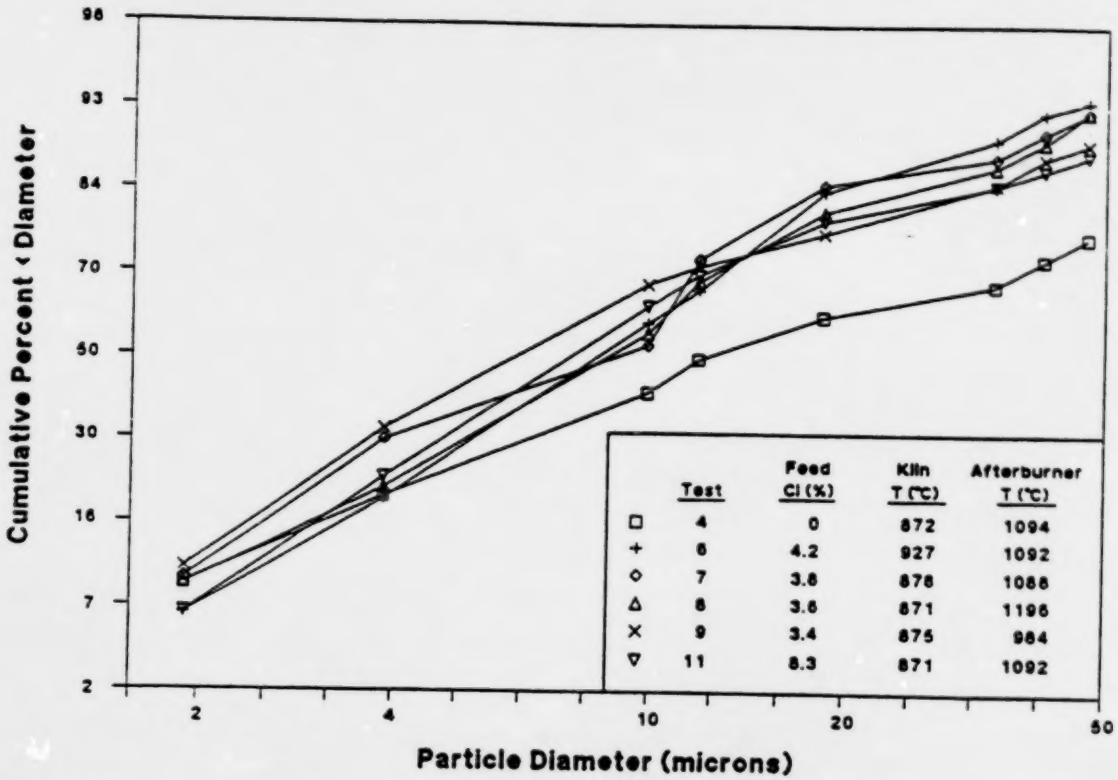


Figure 9. Afterburner exit flue gas size distributions for the parametric trace metal tests.

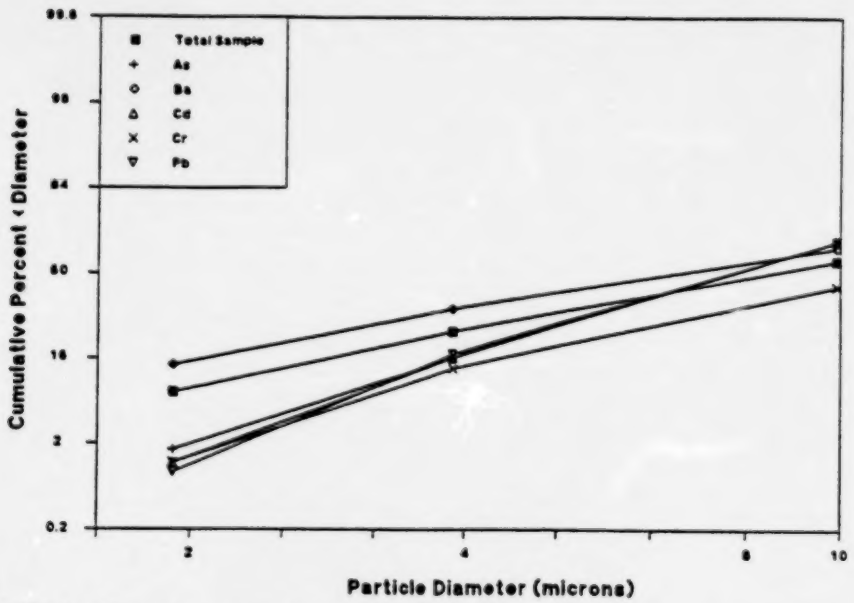


Figure 10(a). Hazardous constituent trace metal size distributions in afterburner exit flue gas particulate for the parametric trace metal tests.

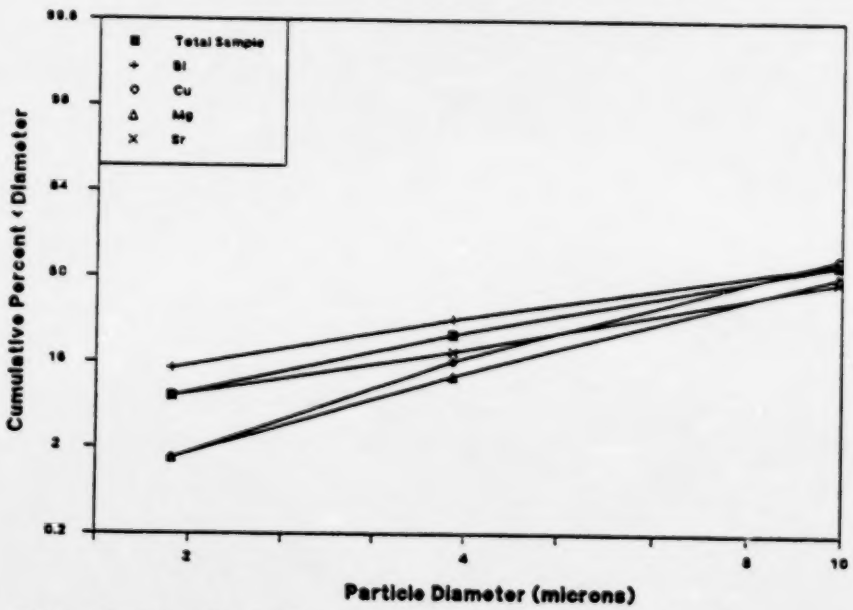


Figure 10(b). Nonhazardous trace metal size distributions in afterburner exit flue gas particulate for the parametric trace metal tests.

3.2.6 Chromium Valence State Distributions

Chromium discharge distributions for the focused chromium valence state tests, expressed as fractions of total measured chromium, are tabulated in Table 4. It is clear that, in these tests as well, chromium remained predominantly in the kiln ash (greater than 80 percent of the total measured). The scrubber exit flue gas and blowdown liquor streams combined accounted for less than 5 percent of the discharged chromium with no feed chlorine. With chlorine in the feed, the flue gas chromium fraction doubled to about 4 percent. Similarly, the scrubber blowdown liquor chromium fraction increased to about 11 percent.

Table 5 summarizes the fraction of the total chromium in feed and discharge streams analyzed as being Cr(+6). As shown, the feed was 52 percent Cr(+6) for the test with Cr(+6) spiked into the feed and was analyzed as 2 percent Cr(+6) for the tests with Cr(+3) spiked into the feed. For all tests, the kiln ash chromium was comprised of negligible amounts of Cr(+6).

The scrubber exit flue gas Cr(+6) fraction was the same (12 to 16 percent) regardless of whether Cr(+6) was present in the feed, provided there was no feed chlorine. In contrast, for the case in which the feed contained chlorine, roughly half the scrubber exit flue gas chromium was Cr(+6). This would be expected if some of the entrained particulate chromium from the kiln vaporized in the hotter afterburner and reacted with the flue gas chlorine to form chromyl chloride (CrO_2Cl_2), a relatively stable compound with chromium as Cr(+6).

The scrubber liquor Cr(+6) fraction for the test with Cr(+6) in the feed was significantly higher than for the other two tests with only Cr(+3) in the feed. This is as expected if some of the chromium in the scrubber inlet flue gas was present as soluble Cr(+6) species ($CrO_4^=$ and $Cr_2O_7^=$).

3.3 CONCLUSIONS

Test conclusions include:

- The observed metal volatilities, based upon normalized discharge distribution data, generally agree with theoretical predictions based on volatility temperature. A notable exception was arsenic, which is theoretically the most volatile metal; it exhibited one of the lowest observed volatilities.

- Cadmium, bismuth, and lead were relatively volatile, with an average of less than 32 percent of the discharge metal accounted for by the kiln ash. Barium, copper, strontium, chromium, magnesium, and arsenic were more refractory, with greater than 75 percent of the metal discharge accounted for by the kiln ash.

- Apparent venturi/packed column scrubber collection efficiencies decrease as metal volatility increases

- Increasing feed chlorine content measurably increased the volatility of the volatile metals (cadmium, lead, and bismuth) and of copper (less volatile)

- Consistent with expectation, increasing kiln temperature tends to slightly decrease the fraction of volatile metal accounted for by the kiln ash

TABLE 4. TOTAL CHROMIUM DISCHARGE DISTRIBUTIONS FOR THE CHROMIUM VALENCE STATE TEST SERIES

	Total Cr fraction (percent of measured)		
	Test 1 Cr(+6) feed, no Cl	Test 2 Cr(+3) feed, no Cl	Test 3 Cr(+3) feed, 8.5% feed Cl
Kiln ash	95.5	95.2	84.4
Scrubber exit flue gas	1.3	1.8	4.2
Scrubber liquor	3.2	3.0	11.4
Total	100.0	100.0	100.0
Apparent scrubber Cr removal efficiency	71	63	73

TABLE 5. HEXAVALENT CHROMIUM FRACTION FOR THE CHROMIUM VALENCE STATE TEST SERIES

	Cr(+6)/total Cr(percent)		
	Test 1 Cr(+6) feed, no Cl	Test 2 Cr(+3) feed, no Cl	Test 3 Cr(+3) feed, 8.5% feed Cl
Composite feed	52	2	2
Kiln ash	0.3	0.2	0.1
Scrubber exit flue gas	12	16	48
Scrubber liquor	57	21	28

- Discharge distributions of the nonvolatile metals were generally unaffected by variations in the test variables over the range tested

- Afterburner exit flue gas particle size distributions were roughly log-normal; the presence of chlorine appeared to shift the particles to a finer distribution

- In the scrubber exit flue gas, chromium exists predominantly in the trivalent form regardless of valence state in the feed, provided the feed contained no chlorine; its hexavalent fraction increased in the test where chlorine was present in the feed

Test results were documented in the test report:

- D. J. Fournier, Jr., W. E. Whitworth, Jr., J. W. Lee, and L. R. Waterland, "Pilot Scale Evaluation of the Fate of Trace Metals in a Rotary Kiln Incinerator with a Venturi Scrubber/Packed Column Scrubber," draft April 1989, revised October 1989.

In addition, test results were presented in two technical papers:

- L. R. Waterland, D. J. Fournier, Jr., W. E. Whitworth, "Pilot-Scale Testing to Evaluate the Fate of Trace Metals in Rotary Kiln Incineration." Presented at the 1989 Summer National AIChE Meeting, Philadelphia, Pennsylvania. August 1989.

- G. J. Carroll, R. C. Thurnau, R. E. Mournighan, L. R. Waterland, J. W. Lee, and D. J. Fournier, Jr. "The Partitioning of Metals in Rotary Kiln Incineration," presented at the Third International Conference on New Frontiers for Hazardous Waste Management, Pittsburgh, Pennsylvania. September 1989.

SECTION 4

TRACE METAL EMISSION AND DISCHARGE TESTING IN THE ROTARY KILN SYSTEM WITH THE IONIZING WET SCRUBBER

Section 3 discussed the results from a series of tests to evaluate the fate of trace metals in a rotary kiln incinerator equipped with a venturi scrubber/packed column scrubber for particulate and acid gas removal. As noted in Section 3, the primary objective of the tests was to establish a data base of emission and residual discharge trace metal composition to support OSW hazardous waste incinerator trace metal regulation development. To this end, data on the relative performance of different APCSs in controlling flue gas emissions of the trace metals of concern are of high interest to OSW. Thus, a second series of trace metal evaluation tests was completed during FY89 with an IWS used instead of the venturi scrubber/packed column scrubber combination for particulate and acid gas control.

The IWS test series consisted of nine tests and was completed over a 4-week period from late July to mid-August 1989. In addition to supporting the OSW objectives noted above, a sampling team supported by EPA's Atmospheric Research and Emissions Assessment Laboratory (AREAL, T. Ward, coordinator) performed simultaneous sampling during several tests of flue gas emissions as part of a metals sampling method validation study. The following subsections discuss the scope of the tests performed and preliminary test results.

4.1 TEST PROGRAM

This test program was conducted in the RKS after its reconfiguration (discussed in Section 2.2). The major differences in the RKS configuration for this test program compared to the venturi/packed column scrubber test program discussed in Section 3 were:

- A new burner with fuel and air supply flow measurement and control system was installed prior to this test program
- The IWS was installed and used as the primary APCS instead of the venturi/packed column scrubber

Figure 11 is a simplified schematic of the RKS configuration employed for these tests; Table 6 gives the design characteristics of the key system components.

4.1.1 Synthetic Waste Mixture

The basic feed material for these tests was essentially the same as that used for the venturi/packed column scrubber tests discussed in Section 3. It consisted of an organic liquid mixture containing toluene and varying amounts of chlorobenzene and tetrachloroethylene, to vary mixture chlorine content, combined with a clay absorbent in the ratio of 0.4 kg organic liquid to 1 kg clay. As for the venturi/packed column scrubber tests, feed chlorine content was

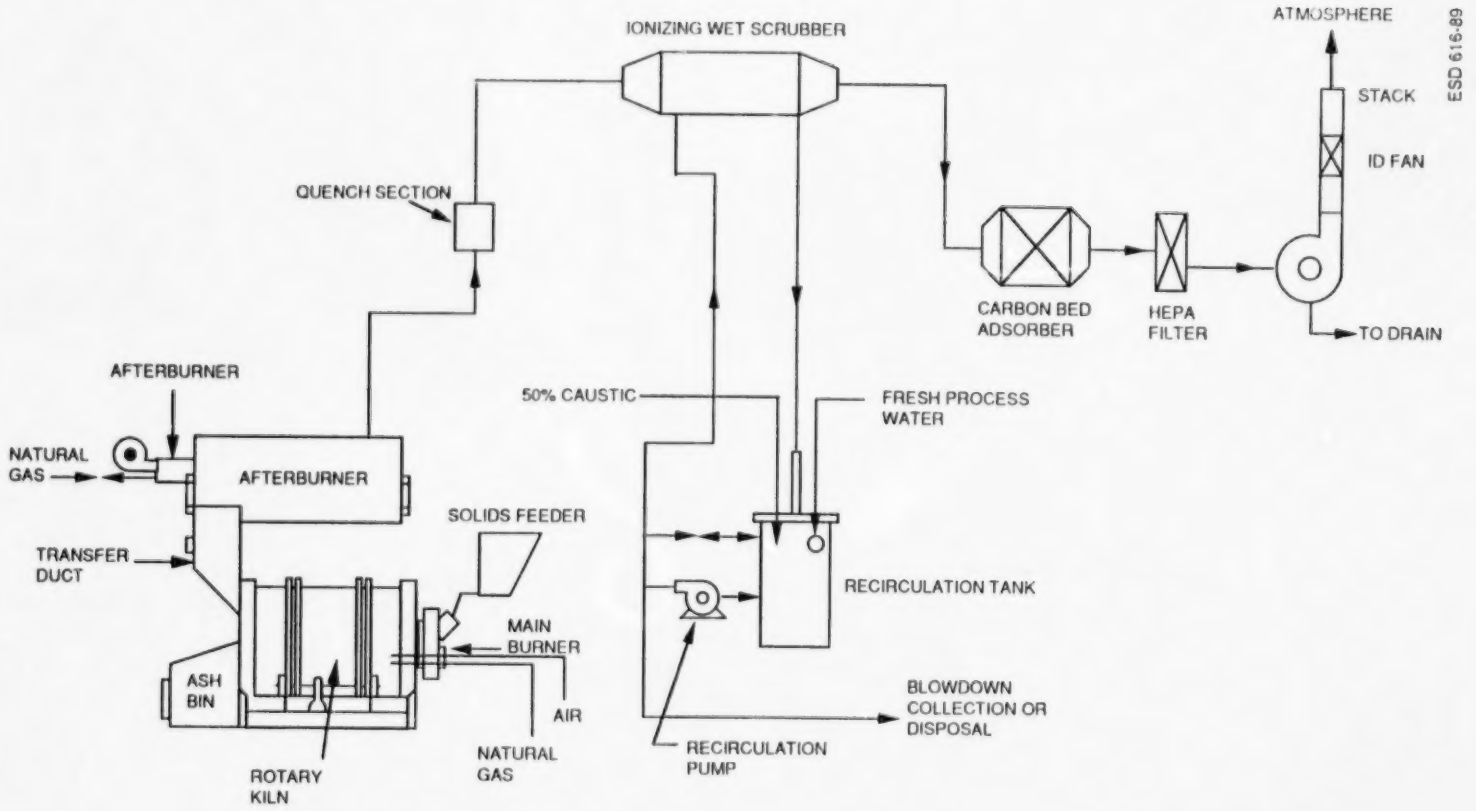


Figure 11. Schematic of the IRF rotary kiln system for the IWS trace metal tests

TABLE 6. DESIGN CHARACTERISTICS OF THE IRF ROTARY KILN SYSTEM FOR THE IWS TRACE METAL TESTS

Characteristics of the Kiln Main Chamber

Length, outside	2.61 m (8 ft - 7 in)
Diameter, outside	1.22 m (4 ft)
Length, inside	2.44 m (8 ft)
Diameter, inside	0.95 m (3 ft - 1-1/2 in)
Chamber volume	1.74 m^3 (61.4 ft^3)
Construction	0.63 cm (0.25 in) thick cold rolled steel
Refractory	12.7 cm (5 in) thick high alumina castable refractory, variable depth to produce a frustroconical effect for moving solids
Rotation	Clockwise or counterclockwise 0.2 to 1.5 rpm
Solids retention time	1 hr (at 0.2 rpm)
Burner	North American burner, rated at 590 kW (2.0 MMBtu/hr) with liquid feed capability
Primary fuel	Natural gas
Feed system	
Liquids	Positive displacement pump via water-cooled lance
Sludges	Moyno pump via front face, water-cooled lance
Solids	Metered twin-auger screw feeder or fiber pack ram feeder
Temperature	1,010°C (1,850°F)

Characteristics of the Afterburner Chamber

Length, outside	3.05 m (10 ft)
Diameter, outside	1.22 m (4 ft)
Length, inside	2.74 m (9 ft)
Diameter, inside	0.91 m (3 ft)
Chamber volume	1.80 m^3 (63.6 ft^3)
Construction	0.63 cm (0.25 in) thick cold rolled steel
Refractory	15.24 cm (6 in) thick high alumina castable refractory
Gas residence time	1.2 to 2.5 sec depending on temperature and excess air
Burner	North American burner rated at 590 kW (2.0 MMBtu/hr) with liquid feed capability
Primary fuel	Natural gas
Temperature	1,200°C (2,200°F)

Characteristics of the Ionizing Wet Scrubber APCD

System capacity inlet gas flow	85 m^3/min (3,000 acfm) at 78°C (172°F) and 101 kPa (14.7 psia)
Pressure drop	1.5 kPa (6 in wc)
Liquid flow	15.1 L/min (4 gpm) at 345 kPa (50 psig)
pH control	Feed back control by NaOH solution addition

a test variable. The three target chlorine concentrations in the clay/organic liquid mixture were 0, 4, and 8 percent.

As also done in the venturi/packed column scrubber tests, most of the trace metals were introduced into the feed by adding them in aqueous solution to the clay/organic liquid mixture at the head of the kiln screw feeder. Since the clay contained sufficient quantities of chromium and magnesium (equivalent to about 50 ppm Cr and 1.7 percent Mg in the final feed mixture), these were not added to the aqueous spike solution. Solution concentrations of several of the other metals differed somewhat from the concentrations used in the venturi/packed column scrubber tests. Table 7 summarizes the target feed metal concentrations (Cr and Mg excepted) for the IWS tests.

4.1.2 Test Conditions

The test variables for the test series were the same as those for the parametric venturi/packed column scrubber tests. These were the chlorine content of the feed synthetic waste, kiln temperature, and afterburner temperature. Seven specific combinations of these as test points were tested based on a factorial experimental design for three variables varied over three levels. One test condition was tested in triplicate to give a measure of measurement precision and to serve as the trial burn for the RKS/IWS system configuration.

Feed mixture chlorine content was varied from 0 to 8 percent, kiln temperature from targets of 816° to 927°C (1500° to 1700°F), and afterburner temperature from targets of 982° to 1204°C (1800° to 2200°F). Table 8 gives the target values for each of the test variables for the seven test points specified by the factorial experimental design algorithm. The seventh and eight test points were the replicates of Test Point 4.

All tests were to be performed at the same nominal kiln exit flue gas O_2 (11.5 percent), afterburner exit flue gas O_2 (8.0 percent), and synthetic waste feedrate (63 kg/hr (140 lb/hr) of which 18 kg/hr (40 lb/hr) is the organic liquid matrix).

No chromium valence state testing was performed in this test series.

4.1.3 Sampling and Analysis

The sampling and analysis protocol employed for these tests was essentially the same as that employed in the parametric venturi/packed column scrubber tests as discussed in Section 3.1.3. In general, sampling for each test consisted of obtaining:

- A composite sample of all feed materials (clay/organic liquid and aqueous metal spike solution)
- A composite sample of the kiln ash
- Several samples of the scrubber blowdown water over time
- Samples of the flue gas at the afterburner and scrubber exits for particulate collection by size (afterburner exit only) and for metal capture in the particulate and backup impinger train
- Samples of the flue gas at the afterburner and scrubber exits for volatile organic hazardous constituents using a volatile organic sampling train (VOST)

TABLE 7. TARGET METAL SPIKE CONCENTRATIONS FOR THE IWS TESTS

	Spike Solution			
Metal	Metal concentration (g/L)	Compound	Compound concentration[a] (g/L)	Resulting waste feed metal concentration[b] (ppm)
Hazardous Constituent Trace Metals				
Arsenic	3.23	As_2O_3	4.26	50
Barium	25.8	$Ba(NO_3)_2$	49.1	400
Cadmium	0.65	$Cd(NO_3)_2 \cdot 4H_2O$	1.8	10
Lead	3.23	$Pb(NO_3)_2$	5.2	50
Other Metals				
Bismuth	25.8	$Bi(NO_3)_3 \cdot 5H_2O$	59.9	400
Copper	25.8	$Cu(NO_3)_2 \cdot 3H_2O$	98.1	400
Strontium	25.8	$Sr(NO_3)_2$	62.3	400

[a]Add sufficient HNO_3 to maintain lead arsenate compounds and bismuth nitrate in solution
[b]Synthetic waste feedrate of 63 kg/hr (140 lb/hr), spike solution feedrate of 1 L/hr

TABLE 8. TARGET TEST CONDITIONS

Test	Feed mixture Cl content, percent	Kiln exit temperature, °C (°F)	Afterburner exit temperature, °C (°F)
1	0	871 (1600)	1,093 (2000)
2	4	816 (1500)	1,093 (2000)
3	4	927 (1700)	1,093 (2000)
4	4	871 (1600)	1,093 (2000)
5	4	871 (1600)	982 (1800)
6	4	871 (1600)	1,204 (2200)
7[a]	4	871 (1600)	1,093 (2000)
8[a]	4	871 (1600)	1,093 (2000)
9	8	871 (1,600)	1,093 (2,000)

[a]Test points 7 and 8 are replicates of test point 4

- Continuous monitor sampling of flue gas O_2, CO_2, and NO_x and total unburned hydrocarbon (TUHC) at the kiln, afterburner, and scrubber exits and in the stack

Figure 12 identifies the nominal location of the sampling points. Table 9 summarizes the specific sampling and analysis procedures used.

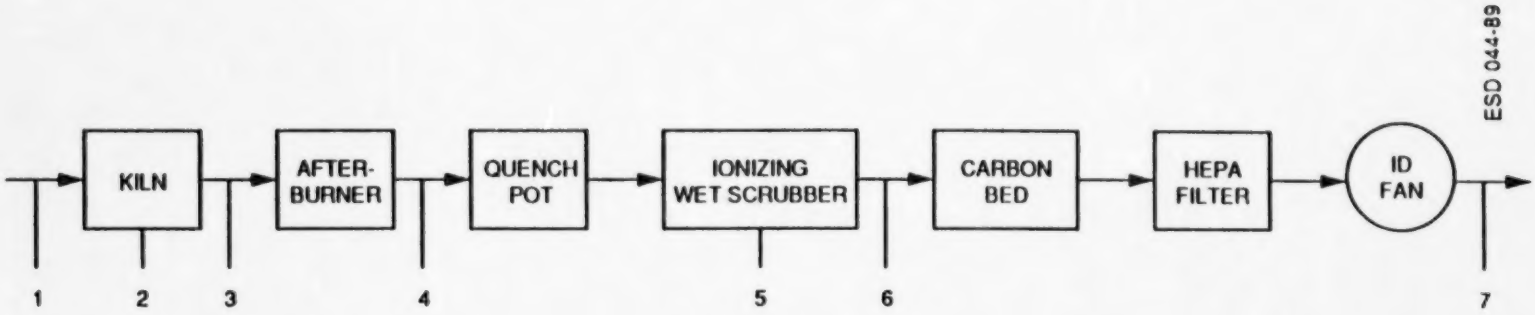
All the sampling and analysis procedures noted in Table 9 are standard methods with the exception of the sampling methods for flue gas metals. The Methods 17 and 5 procedures used to collect flue gas samples for metals analysis at the afterburner exit and IWS exit, respectively, employed reference method sampling trains with impinger contents formulated for metal capture. Impinger contents used were as noted in Table 10.

In addition, Method 17 train at the afterburner exit collected particulate in an oversized thimble placed within the sampling probe. After obtaining the total particulate weight, the particulate in these samples was divided according to terminal velocities in air using a centrifugal classifier. This device is described in the ASME Power Test Code 28.[7] After classification, individual size cut samples were combined into five size ranges for analysis. The five size ranges are nominally <2, 2 to 4, 4 to 10, 10 to 30, and >30 μm.

4.2 TEST RESULTS

As noted in the introductory paragraphs to Section 4, the tests were completed in mid-August 1989. Table 11 lists the test incinerator operating conditions achieved (temperatures and flue gas O_2 levels) and compares these to respective target conditions. Figure 13 presents a graphical summary of the incinerator temperature data from Table 11.

Figure 13 illustrates that average kiln temperatures achieved compared favorably with target kiln temperatures (within 16°C (79°F)) for all tests except Test 1. For this test, average kiln temperature was 25°C (52°F) higher than target. Average afterburner temperature was within 10°C (18°F) of target for all tests at the midpoint target afterburner temperature (1093°C



SAMPLE LOCATIONS

Sampling Point	Feeds and Residuals				Continuous Monitors				Flue Gas			
	Clay Organic Liquid	Metal Spike Solution	Kiln Ash	Scrubber Blowdown	O_2	CO, CO_2	NO_x	Unheated TUHC	Method 17 With Multiple Metals Impingers (Particulate and Metals)	Method 5 With Multiple Metals Impingers (Particulate and Metals)	VOST (Volatile Organics)	Method 5 (Particulate and HCl)
1	X	X										
2			X									
3					X							
4					X	X		X	X		X	
5				X								
6					X	X	X			X		
7					X	X		X			X[a]	X

[a] Tests 4, 7, and 8 only.

Figure 12. IWS test sampling protocol.

TABLE 9. SAMPLING AND ANALYSIS MATRIX FOR THE IWS TRACE METAL TESTS

Sample	Location	Sampling procedure	Analysis		Frequency
			Parameter	Method	
Clay/organic liquid material	Kiln inlet	S005[a]	C_7H_8, C_2Cl_4, C_6H_5Cl	Purge and trap by Method 5030[b] GC/FID analysis[c]	1 composite/test
			Ultimate analysis (C, H, O, Cl)	A003[a]	1 composite/ formulation
			Cr and Mg	Parr bomb ashing[d], digestion by Method 3050[b], ICAP analysis by Method 6010[b]	1 composite/test
Aqueous metal spike solution	Kiln inlet	Composite	As	Digestion and furnace AA by Method 7060[b]	1 composite/test
			Pb	Digestion by Method 3020, furnace AA by Method 7421[b]	1 composite/test
			Ba, Cd, and Cu	Digestion by Method 3010, ICAP analysis by Method 6010[b]	1 composite/test
			Bi and Sr	Digestion by Method 3010,[b] AA analysis by Method 303A[e] (Bi) and 326A[e] (Sr)	1 composite/test
Kiln ash	Kiln ash pit	S005[a]	As	Digestion by Method 3050, furnace AA by Method 7060[b]	1/test
			Pb	Digestion by Method 3020, furnace AA by Method 7421[b]	1/test
			Ba, Cd, Cr, Cu, and Mg	Digestion by Method 3050, ICAP analysis by Method 6010[b]	1/test
			Bi and Sr	Digestion by Method 3050[b] AA analysis by Method 303A[e] (Bi) and 326A[e] (Sr)	1/test

(continued)

[a]Reference 4
[b]Reference 5
[c]Reference 6
[d]Reference 7
[e]Reference 8

TABLE 9. (continued)

Sample	Location	Sampling procedure	Analysis		Frequency
			Parameter	Method	
Kiln ash (continued)			Volatile organic hazardous constituents	Purge and trap by Method 5030[b], GC/FID analysis[c]	1/test, Tests 1, 2, 3, 4, 7, 8, and 9
			TCLP	TCLP extraction,[f]	1/test, Tests 1, 2, 3, 4, 7, 8, and 9
Kiln ash TCLP extract			As	Digestion and furnace AA by Method 7060[b]	1/extract
			Pb	Digestion by Method 3020, furnace AA by Method 7421[b]	1/extract
			Ba, Cd, and Cr	Digestion by Method 3010, ICAP analysis by Method 6010[b]	1/extract
Scrubber blowdown water	Blowdown discharge	Grab/tap	As	Digestion and furnace AA by Method 7060[b]	At least 3/test
			Pb	Digestion by Method 3020, furnace AA by Method 7421[b]	At least 3/test
			Ba, Cd, Cr, Cu, and Mg	Digestion by Method 3010, ICAP analysis by Method 6010[b]	At least 3/test
			Bi and Sr	Digestion by Method 3010[b], AA analysis by Method 303A[e] (Bi) and 326A[e] (Sr)	At least 3/test
			Volatile organic hazardous constituents	Purge and trap by Method 5030[b], GC/FID analysis[c]	1/test
Flue gas	Afterburner exit	Method 17[g]	Particulate load	Method 17[g]	1/test
			Particulate size distribution	ASME PTC 28[h]	1/test

(continued)

[b]Reference 5
[c]Reference 6
[e]Reference 8
[f]Reference 9
[g]Reference 10
[h]Reference 11

TABLE 9. (continued)

Sample	Location	Sampling Procedure	Analysis		Frequency
			Parameter	Method	
Flue gas (continued)	Afterburner exit (continued)		HCl	Analysis of impinger solution for Cl by specific ion electrode[c]	1/test
			As	Digestion by Method 3050, furnace AA by Method 7060[b] (impingers and particulate by size)	1/test
			Pb	Digestion by Method 3020, furnace AA by Method 7421[b] (impingers and particulate by size)	1/test
			Ba, Cd, Cr, Cu, and Mg	Digestion by Method 3010 or 3050, ICAP analysis by Method 6010[b] (impingers and particulate by size)	1/test
			Bi and Sr	Digestion by Method 3010 or 3050[b], AA analysis (impingers and particulate by size) by Methods 303A[e] (Bi) and 326A[e] (Sr)	1/test
			Volatile organic hazardous constituents	Purge trap by Method 5030[b], GC/FID analysis[c]	1/test
		Method 0030[b]	Volatile organic hazardous constituents	Thermal desorption, purge and trap by Method 5040[b], GC/FID analysis[c]	3 trap pairs per test
	Scrubber exit	Method 5[g]	Particulate load	Method 5[g]	1/test
			HCl	Analysis of impinger solution for Cl by specific ion electrode[c]	1/test

(continued)

[b]Reference 5
[c]Reference 6
[e]Reference 8
[g]Reference 10

TABLE 9. (concluded)

Sample	Location	Sampling Procedure	Analysis		Frequency
			Parameter	Method	
Flue gas (continued)	Scrubber exit (continued)		As	Digestion by Method 3050, furnace AA Method 7060[b] (impingers and particulate)	1/test
			Pb	Digestion by Method 3020, furnace AA by Method 7421[b] (impinger and particulate)	1/test
			Ba, Cd, Cr, Cu, and Mg	Digestion by Method 3010 or 3020, ICAP analysis by Method 6010 (impingers and particulate)	1/test
			Bi and Sr	Digestion by Method 3010 or 3050[b], AA analysis (impingers and particulate) by Method 303A[e] (Bi) and 326A[e] (Sr)	1/test
		Method 0030[b]	Volatile organic hazardous constituents	Thermal desorption, purge and trap by Method 5040[b], GC/FID analysis[c]	3 trap pairs/ test
				Thermal desorption, purge and trap GC/MS analysis by Method 5040[b]	3 trap pairs, test 6 only
Stack gas	Stack downstream of carbon bed/HEPA filter	Method 5[g]	Particulate load	Method 5[g]	1/test
			HCl	Analysis of impinger solution for Cl by specific ion electrode[c]	1/test
		Method 0030[b]	Volatile organic hazardous constituents	Thermal desorption, purge and trap by Method 5040[b], GC/FID analysis[c]	3 trap pairs/ test, tests 4, 7, and 8 only

[b]Reference 5
[c]Reference 6
[e]Reference 8
[g]Reference 10

TABLE 10. MULTIPLE METALS TRAIN IMPINGER SYSTEM REAGENTS FOR THE PARAMETRIC TRACE METAL TESTS

Impinger number	Reagent	Quantity
1	Empty	
2	0.1N NaOH	100 mL
3	5 percent HNO_3 and 10 percent H_2O_2	100 mL
4	5 percent HNO_3 and 10 percent H_2O_2	100 mL
5	Silica gel	750g

(2000°F)). However, average afterburner temperature was 35°C (63°F) higher than the target 982°C (1800°F) low afterburner temperature test and 42°C (75°F) lower than the target 1204°C (2200°F) high afterburner temperature test.

Comparing Figure 13 with Figure 3 shows that the variations in incinerator temperatures over a test were greater for the IWS tests than for the analogous venturi/packed column scrubber tests. The venturi/packed column scrubber tests were performed with an automated process control system in place (the American Combustion system noted in Section 2.2). This system was returned to the vendor, as also discussed in Section 2.2. Its replacement at the time of the IWS tests was a manual system which did not allow fine tuned control of incinerator operation. In addition, this test series was completed immediately after the installation of a new burner and burner management system in the RKS. The tests exhibiting the greatest variations in test temperature were tests 9 and 4. These were the first two tests performed after system restart. The lesser variations in operating temperatures in subsequent tests reflect increased operating experience with a new system.

The data in Table 11 show that average afterburner exit flue gas O_2 achieved agreed well with the target level of 8.0 percent. Kiln exit flue gas O_2 was generally higher than the target level of 11.5 percent. However, it was generally comparable from test to test at about 12.5 percent.

At the end of FY89, test sample analyses and data evaluation and interpretation were underway. These will be completed and test results reported in FY90.

TABLE 11. ACTUAL VERSUS TARGET OPERATING CONDITIONS FOR THE IWS TESTS

Test	Test date	Kiln exit						Afterburner exit					
		Temperature °C (°F)				Flue gas O_2 (%) (Target: 11.5%)		Temperature °C (°F)				Flue gas O_2 (%) (Target: 8.0%)	
			Actual						Actual				
		Target	Minimum	Maximum	Average	Range	Average	Target	Minimum	Maximum	Average	Range	Average
1	8/17/89	871 (1600)	883 (1622)	971 (1682)	900 (1652)	11.1 to 14.9	13.6	1093 (2000)	1076 (1969)	1097 (2006)	1088 (1990)	7.6 to 9.0	8.3
2	8/02/89	815 (1500)	791 (1455)	840 (1544)	819 (1507)	7.9 to 13.4	12.3	1093 (2000)	1083 (1981)	1109 (2029)	1095 (2002)	6.4 to 8.7	7.7
3	8/09/89	927 (1700)	907 (1665)	951 (1744)	929 (1704)	10.1 to 13.3	11.9	1093 (2000)	1073 (1964)	1108 (2026)	1092 (1998)	5.8 to 8.3	7.3
4	8/01/89	871 (1600)	802 (1476)	961 (1762)	877 (1610)	9.0 to 16.6	11.9	1093 (2000)	1083 (1982)	1124 (2055)	1096 (2006)	4.5 to 11.8	7.3
5	8/16/89	871 (1600)	865 (1589)	895 (1643)	885 (1625)	9.0 to 15.5	12.1	1204 (2200)	1145 (2093)	1176 (2148)	1163 (2125)	5.2 to 8.8	7.9
6	8/15/89	871 (1600)	868 (1595)	906 (1663)	887 (1629)	8.5 to 13.4	11.9	982 (1800)	1011 (1851)	1027 (1880)	1017 (1863)	5.4 to 9.4	8.6
7	8/09/89	871 (1600)	862 (1584)	904 (1659)	881 (1618)	11.0 to 13.2	12.6	1093 (2000)	1074 (1965)	1114 (2037)	1103 (2018)	6.0 to 8.2	7.6
8	8/11/89	871 (1600)	858 (1577)	906 (1663)	879 (1615)	11.8 to 13.6	12.6	1093 (2000)	1078 (1973)	1118 (2044)	1098 (2008)	7.5 to 8.7	8.1
9	7/28/89	871 (1600)	800 (1471)	946 (1734)	881 (1617)	14 to 17.2	14.8	1093 (2000)	1074 (1984)	1104 (2019)	1087 (1988)	6.7 to 10.5	8.1

ESD T0521

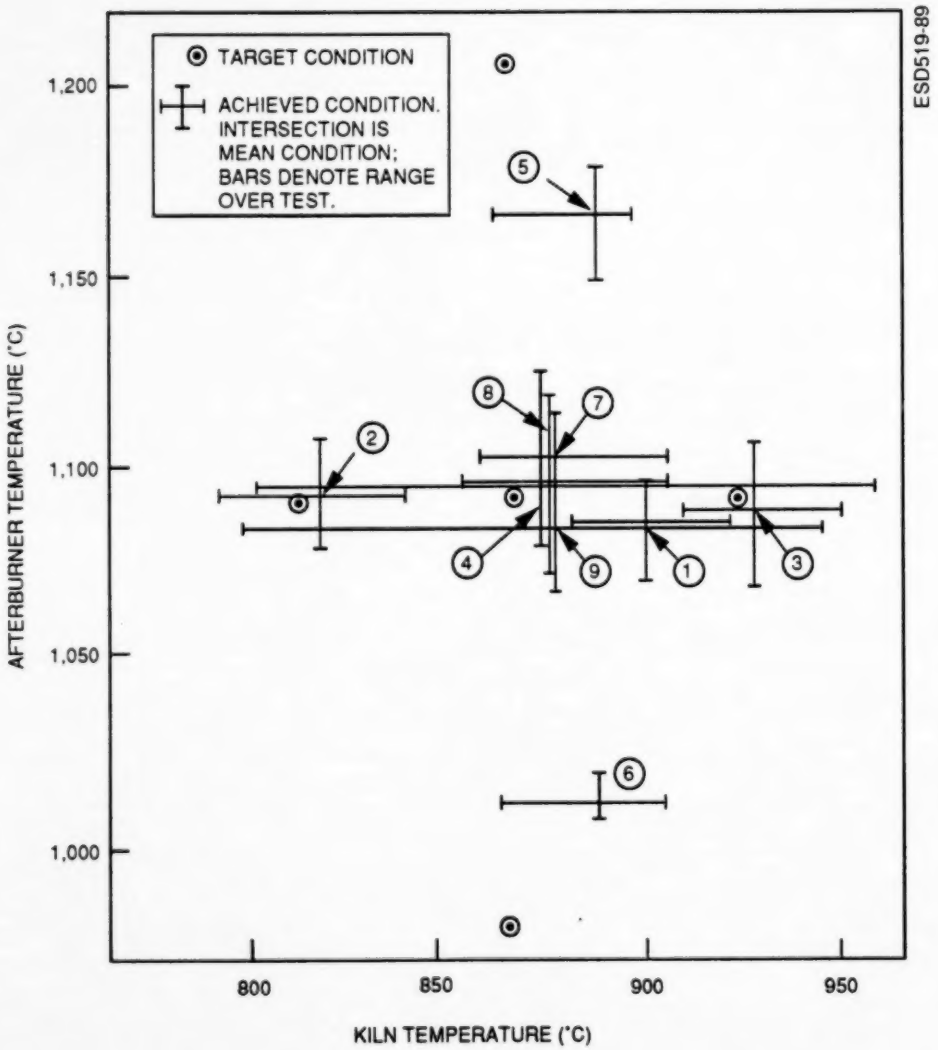


Figure 13. Actual versus target operating conditions for the IWS trace metal tests.

SECTION 5

INCINERABILITY TEST OF A CONTAMINATED SUPERFUND SITE SOIL

One of the primary missions of the IRF is to support EPA Regional Offices in evaluations of the potential of incineration as a treatment option for contaminated soils at Superfund sites. One priority site in Region I is the Baird and McGuire site in Holbrook, Massachusetts. EPA Region I (M. Sanderson, P. Fitzsimmons, Region I; J. Ehresmann, COE, Coordinators) requested that test burns of contaminated soil from this site be performed at the IRF during FY89 to support evaluations of the suitability of incineration as a treatment technology for this soil.

With respect to the incinerability evaluation, the primary concern is whether incineration will effectively destroy the organic contaminants in the soils. A secondary concern relates to the fact that the site soil is contaminated to varying degrees with arsenic and lead. The fate of arsenic and lead in soil when it is subjected to incineration is currently unknown.

The purpose of these tests was to evaluate the incinerability of the Baird and McGuire site soils with regard to organic constituent destruction and to identify the distribution of arsenic in the discharge streams during incineration of arsenic-contaminated soil. The test burn was designed to evaluate the effects of varying incinerator operating conditions on organic contaminant destruction and on the fate of arsenic in the soil. Determining the effectiveness of the air pollution control system in removing any flue gas arsenic and lead was also a test objective. Analysis of the bottom ash will indicate whether treatment by incineration will generate a soil environmentally suitable for redeposit at the Superfund site during full-scale remediation.

5.1 TEST PROGRAM

The test program for the Baird and McGuire soil evaluation had two components. Initially a series of bench scale experiments was performed to evaluate the leachability characteristics of the arsenic and the lead in the soil after incineration as a function of the arsenic/lead concentration in the soil. Incineration of soil samples was simulated by heating them to incineration temperatures in a muffle furnace.

The second component of the test program consisted of a set of five incineration tests in the RKS at the IRF. These tests were aimed at determining the fate of the arsenic and lead in the soil as a function of kiln temperature and kiln excess air level. These tests were performed in the RKS with the IWS in place as the primary APCS. A schematic of the RKS in this configuration is provided in Figure 11; the design characteristics of the system are summarized in Table 6.

5.1.1 Test Soil Characteristics

Contaminated soil for the tests was excavated from the site during August 1989. Three soil types were obtained for testing. For the muffle furnace tests, relatively small (about 5 kg) samples each of soil from an area known to contain soil with high levels of arsenic contamination and from an area known to be relatively uncontaminated by arsenic were obtained. For the parametric incineration tests, a bulk sample (nominally 1350 kg or 3000 lb) was excavated, mixed at the site in an attempt to give a uniform sample, and packaged into six 55-gal drums.

The two muffle furnace samples and a characterization sample of each of the incineration test drums were forwarded to the IRF, the former for muffle furnace testing and the latter for characterization analyses prior to accepting the bulk shipment for testing. The two muffle furnace test samples were analyzed for arsenic and lead and subjected to toxicity characteristic leaching procedure (TCLP) extraction with extracts analyzed for arsenic and lead. Results are summarized in Table 12. As shown, the highly contaminated soil contained about 650 ppm As and 45 ppm Pb. The background (uncontaminated) soil contained negligible (<5 ppm) As and 14 ppm Pb. Most of the As and Pb in both soils was relatively immobile with respect to TCLP extraction.

The characterization samples received were composited into a single sample which was analyzed for semivolatile POHCs. Results are shown in Table 13. Of the semivolatile organic hazardous substance list (HSL) compounds, only p,p´-DDT and its derivatives were found above method detection limits.

5.1.2 Muffle Furnace Test Plan

As noted in the introduction to Section 5, the fate of arsenic and lead during incineration of the site soil is uncertain. In an actual site remediation via incineration, soil with very high arsenic/lead levels can be blended with soil of low arsenic/lead contamination to give an incineration feed which results in a low concentration of leachable arsenic in the kiln ash. But, the a priori unknown is how low the feed arsenic concentration must be.

The objective of the muffle furnace tests was to develop the data to suggest appropriate maximum feed arsenic/lead concentrations. In the tests performed, nine samples were prepared, as outlined in Table 14. Each sample was heated in a muffle furnace at 982°C (1800°F) for 1 hr. The weight loss (moisture and volatiles) was determined for each sample. Then each resulting ash was analyzed for As and Pb, and TCLP leachates of each were also analyzed for As and Pb.

5.1.3 Incineration Testing

A separate series of pilot-scale incineration tests was also performed in the RKS at the IRF. The primary objectives of these tests were to establish that incineration effectively destroys the organic contaminants in the soil, and to evaluate the fate of arsenic and lead during incineration as a function of incineration conditions.

The incineration condition test variables were kiln temperature and kiln excess air level. Kiln temperature was to have been varied from 816 to 982°C (1500 to 1800°F) and excess air from a kiln exit flue gas O_2 of 6 to 10 percent in the matrix shown in Table 15.

TABLE 12. SOIL ARSENIC AND LEAD CONTENT

ESD T0522

Sample	Soil concentration (mg/kg)		TCLP leachate concentration (mg/L)	
	As	Pb	As	Pb
Contaminated soil				
Sample	600	59	0.53	<0.05
Duplicate	710	31		
Average	655	45		
Background soil				
Sample	<5	13.4	<0.07	<0.05
Duplicate	<5	14.4		
Average	<5	14		

TABLE 13. SEMIVOLATILE POHCs IN THE COMPOSITE SOIL SAMPLE

ESD T0523

Compound	Concentration (mg/kg)
p,p'-DDT	650
p,p'-DDE	48
p,p'-DDD	240
Methoxychlor	58
All others	<4

TABLE 14. MUFFLE FURNACE TEST SAMPLES

Sample	Contaminated soil (655 ppm As) (% wt)	Uncontaminated soil (<5 ppm As) (% wt)	Additive
1	100	0	
2	80	20	
3	60	40	
4	50	50	
5	40	60	
6	20	80	
7	0	100	
8	100	0	Add 2% lime to pH >12
9	100	0	Add 2% alum[a]

[a]Ferric ammonium sulfate, $FeNH_4(SO_4)_2$

TABLE 15. TARGET INCINERATION TEST CONDITIONS

Test	Kiln exit temperature	Kiln exit O_2 level (percent)
1	816 (1500)	10
2	816 (1500)	6
3	982 (1800)	10
4	982 (1800)	6
5	Repeat best conditions identified during Tests 1 through 4 for removing arsenic from soil	

In all tests, soil was fed to the kiln in fiber-pack drums via the RKS ram feeder system. Drums containing about 5.0 kg (11 lb) of soil were fed at the rate of one drum every 5 min., for a soil feedrate of 60 kg/hr (132 lb/hr). Kiln rotation rate was set to give a nominal kiln solids residence time of 0.5 hr.

The sampling protocol employed for each test consisted of:

- Obtaining a sample of the scrubber blowdown composited from three grab samples of the scrubber blowdown taken at hourly intervals over the test period
- Obtaining a composite sample of the kiln ash
- Continuously measuring O_2 concentrations downstream of the kiln; O_2 and TUHC concentrations in the afterburner exit; CO, CO_2, NO_x, and TUHC concentrations at the ionizing wet scrubber exit; and O_2, CO, CO_2, and TUHC concentrations in the stack
- Sampling flue gas downstream of the scrubber system for particulate and arsenic using a variation of Method 5
- Sampling the flue gas at the scrubber system exit for semivolatile POHC and pesticides using Method 0010
- Sampling the stack for particulate and HCl using Method 5 to comply with permit requirements

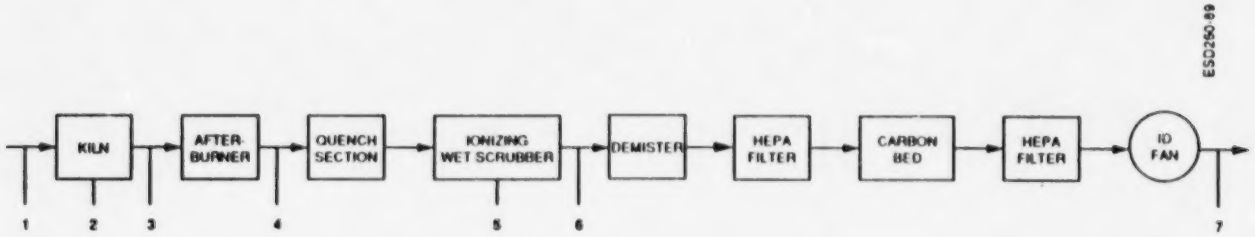
Scrubber exit flue gas was sampled using the same variation of a Method 5 train as specified for multiple metals sampling used in the past trace metal tests as discussed in Sections 3 and 4. Figure 14 identifies the nominal location of the sampling points. Table 16 summarizes the specific sampling and analysis procedures used.

5.2 TEST RESULTS

5.2.1 Muffle Furnace Tests

The muffle furnace tests were performed over a one week time period in early September 1989. Table 17 summarizes the results of these tests in terms of calculated and measured test sample As and Pb content. Several points are illustrated by the data in Table 17. The first is that a relatively constant fraction (about 25 percent) of the soil weight consists of volatile matter (moisture plus volatile organic) for all mixtures of contaminated/background soil. The second is that the ash resulting from the muffling of soil mixtures (no lime or alum additives) has a relatively constant lead content of about 5 ppm. This occurs despite soil mixture lead contents varying from 14 to 45 ppm. Further, a negligible amount of this ash lead is leachable in the TCLP procedure.

The soil As and Pb contents shown in Table 17 can be corrected for the volatile matter content to give corresponding As/Pb concentrations in the nonvolatile (ash) fraction of each soil mixture. These corrected concentrations represent the ash concentrations which would be expected if none of the As/Pb in the soil volatized in the muffle furnace environment. Comparing these corrected concentrations to measured concentrations gives an indication of the fraction of As/Pb present in the soil which volatilized in the high temperature muffle furnace environment. This comparison is tabulated in Table 18.



Sampling Point	Waste Feed	Kiln Ash	Ionizing Wet Scrubber Blowdown	Continuous flue gas monitoring	0010 (Semivolatile Organics)	M5/Metals Train (Particulate, Arsenic)	M5 (Particulate and HCl)
1	X						
2		X					
3				X			
4				X			
5			X				
6				X	X	X	
7				X	X		X

Figure 14. Sampling matrix.

TABLE 16. SAMPLING AND ANALYSIS MATRIX SUMMARY FOR THE SUPERFUND SOIL INCINERATION TESTS

Sample	Location	Sampling Procedure	Analysis		
			Parameter	Method	Frequency
Waste feed	Soil drum during packaging	Composite	Proximate analysis (ash, moisture, heating value)	A001[a]	1 composite
			Ultimate analysis (C, H, O, N, S, and Cl)	A003[a]	1 composite
			TCLP metals	TCLP extraction[b] followed by digestion by Method 3010 and ICAP analysis (Method 6010[c]) for As, Ba, Cd, Cr, Pb, Se, and Ag	1 composite
			Pesticides, designated semivolatile POHC	TCLP extraction[b] with analysis by Method 8270[c]	1 composite/test
				Soxhlet extraction by Method 3540[c], analysis by Method 8270[c]	1 composite/test
			As, Pb	Digestion by Method 3050[c], ICAP analysis by Method 6010[c]	1 composite/test
Kiln ash	Kiln ash pit	Composite	TCLP metals	TCLP extraction[b] followed by digestion by Method 3010 and ICAP analysis (Method 6010[c]) for As, Ba, Cd, Cr, Pb, Se, and Ag	1 composite/test
			Pesticides, designated semivolatile POHC	TCLP extraction[b] with analysis by Method 8270[c]	1 composite/test

[a]Reference 4
[b]Reference 9
[c]Reference 5

TABLE 16. (concluded)

Sample	Location	Sampling Procedure	Analysis		
			Parameter	Method	Frequency
Kiln ash (continued)			As, Pb	Digestion by Method 3050[c], ICAP analysis by Method 6010[c]	1 composite/test
Scrubber blowdown liquor	Blowdown discharge	Composite tap	TCLP metals	TCLP extraction[b] followed by digestion by Method 3010 and ICAP analysis by Method 6010[c] for As, Ba, Cd, Cr, Pb, Se, and Ag	1 composite/test
			Pesticides, designated semivolatile POHC	TCLP extraction[b] (if required) analysis by Method 8270[c]	1 composite/test
Flue gas	Scrubber exit	Method 5[d]	Particulate	Method 5[d]	1/test
			As	Digestion by Method 3050[c] (particulate) or Method 3010[c] (impingers), ICAP analysis by Method 6010[c] for As	1/test
		Method 0010[c]	Pesticides, designated semivolatile POHC	Soxhlet extraction by Method 3540[c], analysis by Method 8270[c]	1/test
Stack gas	Stack, downstream of carbon bed/HEPA filter	Method 5[d]	Particulate	Method 5[d]	1/test

[a]Reference 4
[b]Reference 9
[c]Reference 5
[d]Reference 10

TABLE 17. MUFFLE FURNACE TEST RESULTS

Sample formulation			Calculated soil concentration[a] (mg/kg)		Weight loss on muffling (%)	Ash concentration (mg/kg)		TCLP leachate concentration (mg/L)	
Fraction contaminated soil (%)	Fraction background soil (%)	Lime/alum	As	Pb		As	Pb	As	Pb
100	0		655	45	24.1	468	5.1	13.7	<0.05
80	20		524	39	25.3	351	5.1	13.0	<0.05
60	40		393	33	25.6	310	5.5	9.4	<0.05
50	50		328	30	24.9	299	4.3	9.8	<0.05
40	60		262	26	25.3	211	5.2	7.6	<0.05
20	80		131	20	24.6	130	5.8	4.5	<0.05
0	100		<5	14	25.1	5.1	3.7	<0.07	<0.05
100	0	2% lime	642	44	25.5	716	6.9	6.5	<0.05
100	0	2% alum	642	44	27.0	330	7.4	9.8	<0.05

[a] Based on contaminated soil As of 655 mg/kg and Pb of 45 mg/kg; background soil As of <5 mg/kg and Pb of 14 mg/kg.

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TABLE 18. MUFFLE FURNACE TEST METAL VOLATILITY AT 982°C

Sample formulation			Calculated soil concentration (mg/kg)		Expected ash concentration[b] (mg/kg)		Actual ash concentration (mg/kg)		Fraction remaining with ash[c] (%)	
Fraction contaminated soil (%)	Fraction background soil (%)	Lime/alum	As	Pb	As	Pb	As	Pb	As	Pb
100	0		655	45	863	59	468	5.1	54	9
80	20		524	39	701	52	351	5.1	50	10
60	40		393	33	528	44	310	5.5	59	13
50	50		328	30	437	40	299	4.3	68	11
40	60		262	26	351	35	211	5.2	60	15
20	80		131	20	174	27	130	5.8	75	21
0	100		<5	14	<7	19	5.1	3.7	—	19
100	0	2% lime	642	44	862	59	716	6.9	83	12
100	0	2% alum	642	44	879	60	330	7.4	38	12

[a] Based on contaminated soil As of 655 mg/kg and Pb of 45 mg/kg; background soil As of <5 mg/kg and Pb of 14 mg/kg.
[b] Ash concentration if all soil metal remained with resulting ash in muffle furnace (i.e., soil concentration corrected for soil moisture and organic content).
[c] Actual ash concentration/expected ash concentration.

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The data in Table 18 show that a significant fraction of both the As and Pb in the soil volatilized in the muffle furnace at 980°C (1800°F), as evidenced by actual ash concentrations being uniformly less than expected (no volatilization) ash concentrations. Of perhaps greater interest is the dependence of both As and Pb volatility (fraction volatilized, or 1 minus the fraction remaining with the ash). Only about 25 percent of the As volatilized (75 percent remained with the muffle furnace ash) for the low As content soil mixture. However, up to 50 percent volatilized for the higher As content mixtures. Similar behavior was seen for Pb, although, as noted above, a relatively constant 5 ppm Pb ash resulted for all soil mixtures.

The addition of lime to the contaminated soil clearly decreased the volatility of the As, while the addition of alum significantly increased its volatility. Neither additive effected Pb volatility.

Table 17 noted the TCLP leachate concentration for each ash resulting from the muffle furnace tests. Figure 15 plots the ash TCLP leachate As concentration as a function of both original soil mixture and the resulting ash As concentration. The data in Figure 15 show that a constant fraction of the resultant ash As was mobile as measured by the TCLP leaching procedure. This is indicated by the straight line through the ash data points in Figure 15. Since the TCLP leaching procedure involves producing 20g of leachate per g of ash leached, the quantity of As leachable per g of ash leached is known. The slope of the least square's fit of the ash data points in Figure 15 corresponds to a constant 64 percent of the ash As being leachable.

The curve for the soil data points in Figure 15 falls along the ash curve at low soil As concentration. At these low soil concentrations, a high fraction of the soil As remained with the resultant muffle furnace ash. However, at higher soil mixture As concentrations, a greater fraction of the soil As volatilized; a lesser fraction remained in the resultant ash. This is reflected in the increased deviation of the soil curve from the ash relationship shown in Figure 15.

The addition of lime decreased the As volatility in the soil as noted above, and also decreased the fractional leachability of the resultant ash As. The addition of alum to the soil increased As volatility as noted above, but did not affect the resultant ash As fractional leachability.

The data in Figure 15 suggest that the ash resulting from incinerated soil as produced in the muffle furnace tests would meet the TCLP limit associated with the land disposal restriction of 5 mg/L for soils with As concentrations below about 150 ppm. The data suggest that soils with high As content could be treated with lime and still give an acceptable ash TCLP leachate.

All ash TCLP leachate Pb concentrations were nondetectable (<0.05 mg/L) regardless of initial soil Pb content or whether lime or alum was added to the soil.

5.2.2 Incineration Test Results

The first four (of a planned five) pilot-scale incineration tests of the bulk sample Baird and McGuire site soil were completed during the final week of FY89. Table 19 summarizes the incinerator test operating conditions achieved and compares these to respective target conditions. The data in the table show that average kiln temperatures and exit flue gas O_2 levels were slightly higher than target values, although the agreement with target conditions was quite good. Actual afterburner operating conditions also agreed quite well with target operation.

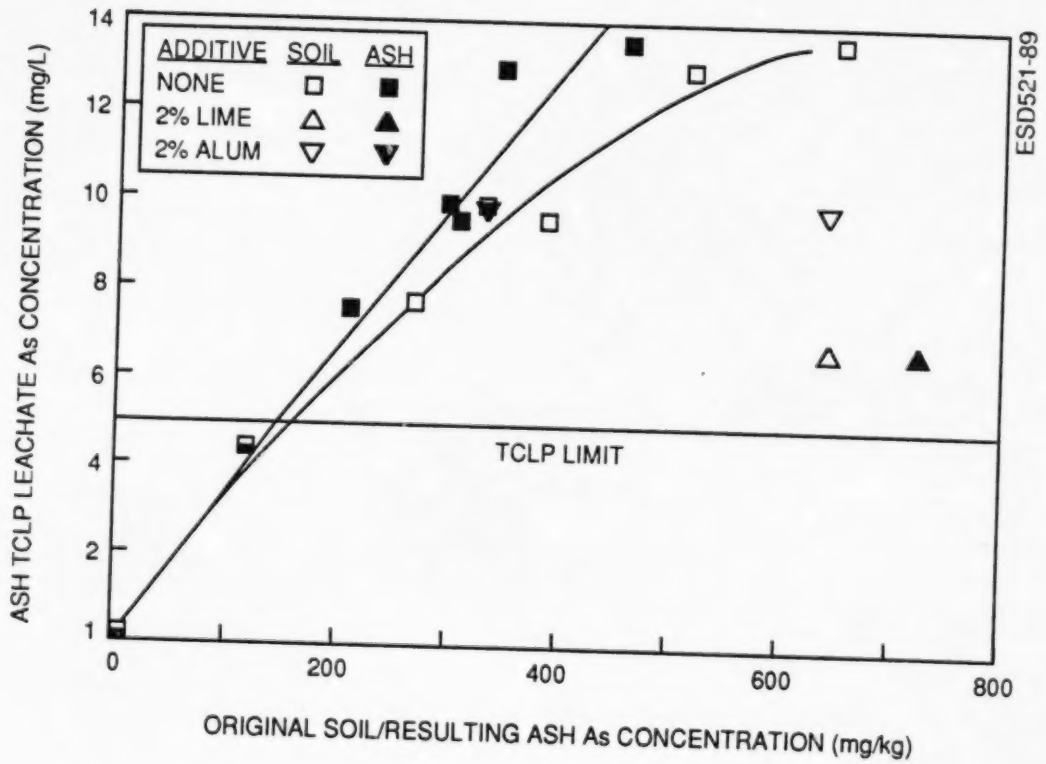

Figure 15. TCLP leachate As concentration versus soil and ash concentration.

TABLE 19. ACTUAL VERSUS TARGET OPERATING CONDITIONS FOR THE BAIRD AND MCGUIRE INCINERATION TESTS

Parameter	Test 1 (9-26-89)	Test 2 (9-29-89)	Test 3 (9-27-89)	Test 4 (9-28-89)
Kiln temperature, °C (°F)				
Target	816 (1500)	816 (1500)	982 (1800)	982 (1800)
Test average	832 (1529)	844 (1552)	994 (1822)	994 (1822)
Test range	794 – 851 (1462 – 1563)	823 – 862 (1514 – 1584)	975 – 1016 (1787 – 1861)	976 – 1017 (1789 – 1863)
Afterburner temperature, °C (°F)				
Target	1093 (2000)	1093 (2000)	1093 (2000)	1093 (2000)
Test average	1094 (2002)	1089 (1993)	1105 (2021)	1099 (2009)
Test range	1086 – 1101 (1987 – 2014)	1081 – 1098 (1978 – 2008)	1095 – 1113 (2003 – 2035)	1092 – 1104 (1977 – 2020)
Kiln exit flue gas O_2, %				
Target	10	6	10	6
Test average	11.3	6.8	10.4	7.5
Test range	9.6 – 17.7	1.9 – 9.6	8.8 – 11.6	4.2 – 9.5
Afterburner exit flue gas O_2, %				
Target	7.5	7.5	7.5	7.5
Test average	7.9	6.3	7.4	7.3
Test range	6.7 – 8.7	4.9 – 7.9	5.7 – 8.6	5.5 – 8.1

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Ash As and Pb concentrations and ash TCLP leachate As and Pb concentrations achieved for various operating conditions were to be used to support the decision on which operating conditions would be repeated as a replicate test 5. Thus, these analyses were performed on a very rapid turnaround basis. Preliminary test results from these analyses are summarized in Table 20.

The data in Table 20 show that the soil feeds for all four initial tests were quite comparable with respect to contaminant metal concentrations. The soil feeds contained between 80 and 94 ppm As and between 16 and 27 ppm Pb. The interesting features of the data in Table 20 are the significant variations in kiln ash metal content and ash TCLP leachate concentrations with the test variables. For the low kiln temperature tests (816°C (1500°F) target), kiln ash As and Pb concentrations were essentially the same as soil feed concentrations. However, for the high kiln temperature tests (982°C (1800°F) target), kiln ash As and Pb concentrations were significantly reduced. This would be as expected; higher kiln temperatures would lead to a greater potential for metal volatilization. Of further interest is the variation in As leachability with kiln excess air level. For both high excess air tests (target kiln exit flue gas O_2 of 10 percent), the ash TCLP leachate As contents were less than for the tests at low kiln excess air (target kiln exit flue gas O_2 of 6 percent).

The data for Pb agree quite well with the results from the muffle furnace tests. In the muffle furnace tests, which were conducted at the same temperature as the high kiln temperature tests, resulting ash Pb concentrations were about 5 ppm regardless of soil Pb concentration. The two high kiln temperature tests resulted in kiln ash with Pb concentrations of 6 and <2 ppm. Further, the ash TCLP leachates were uniformly devoid of Pb, as measured in the incineration tests.

However, the data for As differ in many respects from the muffle furnace test results. The muffle furnace tests results would predict that a soil feed with As content in the 80 to 94 ppm range would yield an ash with about the same As content when incinerated at 982°C (1800°F). This result was observed for the low kiln temperature tests (816°C (1500°F) target), but not for the high kiln temperature tests which were conducted at the muffle furnace test temperature (982°C (1800°F) target). Arsenic was apparently more volatile in the incineration tests than was observed in the muffle furnace tests. In addition, the muffle furnace tests suggested that the fraction of ash As extractable in the TCLP procedure would be about 60 percent regardless of ash As content. This was not observed in any incineration test.

A final point of interest is seen in the data in Table 20. The fraction of soil feed collected as kiln ash is noted in the table for each test. If the incineration test feeds contained 25 percent volatile matter as observed for the muffle furnace test soils, then 75 percent of the soil feed would be collected as kiln ash in the absence of any particulate carryover from the kiln into the afterburner. The fact that the kiln ash discharge fractions noted in Table 20 are uniformly less than 75 percent is consistent with the expectation that significant particulate carryover occurs. Kiln ash discharge fractions ranged from 36 to 60 percent in the tests. The interesting point is that the observed discharge fractions correlated with kiln gas velocity, or flowrate, which is noted in Table 20. The lowest kiln ash fraction occurred for the test with the highest kiln flue gas flowrate (the high temperature, high excess air test). Larger kiln ash discharge fractions occurred for the tests with lower kiln flue gas flowrates. This is as expected. Larger kiln gas velocities or flowrates would lead to greater particulate carryover and correspondingly lower kiln ash discharge fractions.

Based on the preliminary results discussed above, it was decided to perform a replicate test (Test 5) at the low kiln temperature, high kiln excess air condition (Test 1 condition), since

TABLE 20. PRELIMINARY ASH As AND Pb DATA FOR THE BAIRD AND MCGUIRE INCINERATION TESTS

Parameter	Test 1 (9-26-89)	Test 2 (9-29-89)	Test 3 (9-27-89)	Test 4 (9-28-89)
Kiln temperature, °C (°F)	832 (1529)	844 (1552)	994 (1822)	994 (1822)
Kiln exit flue gas O_2, %	11.3	6.8	10.4	7.5
Arsenic concentrations				
Soil feed (mg/kg)	83	82	94	80
Kiln ash (mg/kg)	80	80	35	28
Kiln ash TCLP leachate (mg/L)	0.37	1.2	0.33	1.2
Fraction of kiln ash As leachable (%)[a]	9	30	19	86
Lead concentrations				
Soil feed (mg/kg)	21	16	27	16
Kiln ash (mg/kg)	16	15	6	<2
Kiln ash TCLP leachate (mg/L)	<0.05	<0.05	<0.05	<0.05
Fraction of soil feed discharged as kiln ash (%)	52	60	36	60
Kiln exit flue gas flowrate, dscm/min[b]	5.97	2.86	7.92	4.93
Kiln exit flue gas flowrate, m^3/min[c]	22.8	11.1	34.8	21.6

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[a] TCLP leachate prepared by extracting 100g kiln ash into 2 kg leachate.
[b] Calculated based on fuel composition and exit flue gas O_2 (kiln exit flue gas flowrate not directly measured in tests).
[c] Based on average kiln temperature noted in table, also dry basis (neglects flue gas moisture).

this gave an ash with low TCLP leachate As concentration and low As carryover into the flue gas. Test 5 was completed on October 5, 1989.

Remaining test sample analyses, data evaluation and interpretation, and test reporting will be completed in FY90.

SECTION 6

THIRD PARTY TESTING

The recently passed Federal Technology Transfer Act allows for the use of government facilities and equipment in joint projects with private sector concerns. The IRF represents a unique facility with capabilities unavailable anywhere else in the U.S. Furthermore, the hazardous waste incineration research and testing arena is quite active. Thus, the potential demand for such third party joint projects is expected to be quite significant.

The RREL policy established during FY89 was to encourage and even solicit third party use of the IRF. Accordingly, the IRF operations and research contract was modified in FY89 to provide for this type of usage, and initial efforts to identify appropriate joint third party projects were undertaken.

Toward this end a facility capabilities brochure was prepared. This brochure will be printed and distributed in FY90. The focus of the brochure is to outline the capabilities of the IRF and the type of testing which has and can be performed, and solicit third party inquiries.

Although no active solicitation of third party interest occurred during FY89 (this will begin in FY90) several unsolicited contacts were established. These included:

- Westinghouse Environmental Services—regarding incinerability testing of glycol recovery sludge
- Ebasco Services Incorporated—regarding incinerability testing of wastes from the Sand Springs Superfund site in Oklahoma
- International Technology Corporation (IT)—regarding an evaluation of alternate air pollution control scrubbers
- Chemical Waste Management, Inc.—regarding incinerability testing of a biological sludge from leachate treatment
- Waste-Tech Services—regarding general incineration testing capabilities
- Haynes International—regarding corrosion testing

Discussions with Westinghouse, IT, and Chemical Waste Management led to the preparation of a test program proposal, and requests for proposals are expected from Ebasco and Waste-Tech in FY90. None of the test program proposals prepared to date have culminated in an agreement to perform a joint test program. However, the expectation is that FY90 will see the initiation of third party IRF use.

SECTION 7

EXTERNAL COMMUNICATIONS

During FY89, six reports were prepared and submitted, and seven technical papers were presented. These are listed in Table 21. This level of external communication and technology transfer is comparable to levels experienced over the preceding two years and testifies to the high level of important research being supported at the IRF.

Table 22 lists some of the visitors to the facility during FY89. The length of the list attests to the visibility to the incineration research community of the work being performed at the facility.

TABLE 21. IRF PROGRAM REPORTS AND PRESENTATIONS IN FY89

ESD T0527

Reports

- Waterland, L. R., J. W. Lee, and R. W. Ross, II. "Pilot-Scale Incineration Tests of Wastewater Treatment Sludge from Pentachlorophenol Wood Preserving Processes (K001)." Draft October 1988.
- Waterland, L. R.. "Operations and Research at the U.S. EPA Combustion Research Facility, Annual Report for FY'88." Draft November 1988, revised December 1988.
- Waterland, L.R., and J. W. Lee. "Technology Evaluation Report SITE Demonstration Test, American Combustion Pyretron Thermal Destruction System at the U.S. EPA's Combustion Research Facility." EPA/540/5-89/008a, March 1989.
- Waterland, L. R., C. I. Okoh, and A. S. McElligott. "SITE Program Applications Assessment of Superfund Applications for the American Combustion Inc. Pyretron Oxygen Enhanced Burner." EPA/540/5-89/008b, March 1989.
- Waterland, L. R. and A-K. M. Siag. "Pilot-Scale Evaluation of SF_6 Injection for Compliance Monitoring of Hazardous Waste Incinerators." Draft March 1989.
- Fournier, Jr., D. J., W. E. Whitworth, and L. R. Waterland. "Pilot-Scale Evaluation of the Fate of Trace Metals in a Rotary Kiln Incinerator with a Venturi Scrubber/Packed Column Scrubber." Draft April 1989, revised October 1989.

Papers and Presentations

- Waterland, L. R., and A-K. M. Siag. "Pilot-Scale Evaluation of SF_6 Injection for Compliance Monitoring of Hazardous Waste Incinerators." Presented at the 1989 Spring Meeting of the Western States Section of The Combustion Institute, Paper WSS-89-34, Pullman, Washington, March 1989.
- Thurnau, R. C., J. W. Lee, and L. R. Waterland. "The U.S. EPA Combustion Research Facility." Presented at the Fifteenth Annual Research Symposium on the Remedial Action, Treatment, and Disposal of Hazardous Waste, Cincinnati, Ohio, April 1989.
- Mournighan, R. E., M. K. Richards, and H. Wall. "Incinerability Ranking of Hazardous Organic Compounds." Presented at the Fifteenth Annual Research Symposium on the Remedial Action, Treatment, and Disposal of Hazardous Waste, Cincinnati, Ohio, April 1989.
- Waterland, L. R., J. W. Lee, A-K. Siag, and L. J. Staley. "Pilot-Scale Testing of SF_6 as a Hazardous Waste Incinerator Surrogate." Presented at the 82nd AWMA Annual Meeting and Exhibition, Paper 89-23B.4, Anaheim, California, June 1989.
- Waterland, L. R., D. J. Fournier, Jr., W. E. Whitworth. "Pilot-Scale Testing to Evaluate the Fate of Trace Metals in Rotary Kiln Incineration." Presented at the 1989 Summer National AIChE Meeting, Philadelphia, Pennsylvania, August 1989.
- Carroll, G. J., R. C. Thurnau, R. E. Mournighan, L. R. Waterland, J. W. Lee, and D. J. Fournier, Jr. "The Partioning of Metals in Rotary Kiln Incineration." Presented at the Third International Conference on New Frontiers for Hazardous Waste Management, Pittsburgh, Pennsylvania, September 1989.
- Waterland, L. R., J. W. Lee, and L. J. Staley. "Pilot-Scale Incineration Testing of an Oxygen-Enhanced Combustion System." Presented at the Third International Conference on New Frontiers for Hazardous Waste Management, Pittsburgh, Pennsylvania, September 1989

TABLE 22. VISITORS TO THE IRF

Person	Affiliation	Date	Purpose of visit
J. Oesterle	Ebasco	10-17-88	Facility tour, discuss third party test program
D. McNeilly	NCCI	10-20-88	Facility tour
D. Green	Arkansas Department of Pollution Control and Ecology (ADPCE)	11-18-88	Annual RCRA inspection
M. Stowers, T. Hasting	Earth Technology Corp.	11-14-88	Region VI visual inspection
R. Loftin	U.S. Department of Agriculture	01-31-89	Facility tour
D. Cordle, G. Kernosek	ERM	02-20-89	Facility tour
J. F. Angelo, J. R. Petersen	John Zink	03-09-89	Facility tour, discuss possible third party testing
R. Novak, R. Miller	IT Corp.	03-16-89	Facility tour, discuss third party test program
R. Sawyer, G. Gupta	Enviresponse	03-16-89	Facility tour
B. Keough	ADPCE	03-22-89	Inspect construction progress, discuss permit modification
O. L. Holland	Hydrosonics	03-30-89	Discuss use of pilot scrubber in test program
R. Hall, R. Mourninghan	EPA/AEERL EPA/RREL	05-01-89	Facility tour, project review
T. Ward C. Wen	EPA/AREAL Entropy Environmentalists	06-22-89	Site survey for collaborative AREAL testing
G. Carroll, J. Burkart, H. Wilson, J. Welch, A. O'Hare, B. Young	EPA/RREL EPA/RREL EPA/OARM EPA/OARM Booz, Allen Booz, Allen	07-25-89 through 07-27-89	Perform environmental compliance audit
M. McCorkle, M. Kourehdar	ADPCE	07-27-89	Facility familiarization tour
T. Ward, S. Steinsberger, T. Ovellette, L. Huang, S. Helms	EPA/AREAL Entropy Environmentalists	07-31-89 through 08-03-89	Perform simultaneous trace metal sampling under AREAL collaboration during IWS trace metals tests
J. Trease, A. Belivear	U.S. Army COE Metcalf and Eddy	09-05-89, 09-06-89	Witness Region I Superfund site soil muffle furnace tests

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TABLE 22. concluded

Person	Affiliation	Date	Purpose of visit
M. Richards	EPA/RREL	09-12-89, 09-13-89	Facility tour discusses preparation for Region I Superfund site soil incineration tests
E. Poncelet	National Agency for Waste Disposal and Recovery, France	09-14-89	Facility tour
G. Carroll, H. Wall	EPA/RREL	09-21-89, 09-22-89	Witness Region I test scoping tests
R. Mourninghan, C. Dempsey, R. Thurnau	EPA/RREL	09-27-89, 09-28-89	Witness Region I Superfund soil tests
J. Trease, J. Ehresmann, A. Belivear, J. Tovarnickey, C. Frudkin	U.S. Army COE U.S. Army COE Metcalf & Eddy Metcalf and Eddy EPA/Region I	09-28-89	Witness Region I Superfund soil tests

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SECTION 8

PLANNED EFFORTS FOR FY90

Two major test programs were completed in late FY89: the IWS/trace metal tests discussed in Section 4, and the Baird and McGuire Superfund site soil incinerability tests for Region I, discussed in Section 5. As of the end of FY89, only partial results were available for these tests. Thus, as noted in Sections 4 and 5, remaining test sample analyses, test data reduction and interpretation, and test reporting efforts will continue into FY90. Draft test report submittal for both programs is scheduled for January 1990.

In addition, during FY89 several activities under the facility construction and equipment upgrade effort were not completed before testing activities were reinitiated in July 1989. These efforts will be completed during FY90 and include:

- Replacing the refractory in the kiln chamber of the RKS
- Completing the reconfiguration of the RKS APCS, including:
  - Relocating the venturi scrubber/packed column scrubber to more suitable floor space in the former IRF building area
  - Installing a refractory-lined length of ductwork between the afterburner exit and the relocated quench section of the RKS; this will provide a straight section of refractory lined ductwork of sufficient length to allow isokinetic sampling of hot afterburner exit flue gas
  - Completing the installation of the RKS scrubber liquor heat exchanger system
- Installing and bringing into operation the automated process control system purchased in FY89

The kiln refractory replacement will be completed in October 1989. Remaining efforts to complete the RKS APCS reconfiguration which do not interfere with testing in the RKS will be performed in early FY90. When the reconfiguration effort reaches the point where no further work can proceed while still operating the system, it will be removed from service and the reconfiguration completed. It is expected that this period of downtime will require 4 to 6 weeks beginning in March 1990. The installation, configuration, and shakedown of the automated process control system will be scheduled so that it will be finished at the completion of the entire APCS reconfiguration effort.

With respect to test activities, six major test programs are planned for FY90. These include:

- Incinerability testing of contaminated soils from the Purity Oil Sales and McColl Superfund sites in Region IX (R. Blank, J. Blevins, Coordinators). Initial planning for these tests was begun in FY89. Tests of three materials from the Purity Oil Sales site and two materials from the McColl site are planned for December 1989.

- Parametric testing of the POHC surrogate soup defined by UDRI, is to be performed in January 1990. A systematic evaluation of the relationship between heated and unheated total hydrocarbon monitors is planned in conjunction with these tests.

- Residuals characterization tests to establish best demonstrated available technology treatment standards for spent potliners from the primary reduction of aluminum, listed waste K088, (R. Turner, J. Berlow, Coordinators); planned to be performed in February 1990

- Parametric testing of an organic test mixture including compounds from the entire range of the incinerability index ranking developed by UDRI, planned for April 1990. An evaluation of the accuracy, precision, and reliability of a continuous HCl monitor is planned in conjunction with these tests.

- Testing of the fate of trace metals in the RKS using a third APCS (a Hydrosonics scrubber, a spray dryer/fabric filter combination, or an electrostatic precipitator are candidates), planned to be performed in May 1990. A test matrix designed to evaluate the form and feed method of the metals introduced is planned for these tests.

- Parametric testing of a soil matrix for CERCLA restoration by incineration, and/or another Superfund site waste, planned for July and August 1990

Special studies to be defined, additional Regional Office support, or private sector third party testing have been scheduled for in August and September 1990.

REFERENCES

1. Waterland, L. R., "Operations and Research at the U.S. EPA Combustion Research Facility: Annual Report for FY87," December 1987.

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3. Waterland, L. R., "Operations and Research at the U.S. EPA Combustion Research Facility: Annual Report for FY86," December 1986.

4. Harris, J. C., et al., "Sampling and Analysis Methods for Hazardous Waste Incineration," EPA-600/8-84-002, February 1984.

5. "Test Methods for Evaluating Solid Waste: Physical/Chemical Methods," EPA SW-846, 3rd Ed., November 1986.

6. "Quality Assurance Project Plan for Evaluating the Fate of Trace Metals in Rotary Kiln Incineration with Ionizing Wet Scrubber Particulate/Acid Gas Control," June 1989.

7. Lentzen, D. E., et al., "IERL-RTP Procedures Manual: Level 1 Environmental Assessment (Second Edition)," EPA-600/7-78-201, October 1978.

8. "Standard Methods for the Examination of Water and Wastewater," 16th Edition, APHA, AWWA, WPCF, 1985.

9. 40 CFR Part 268, Appendix I.

10. 40 CFR Part 60, Appendix A.

11. "Determining the Properties of Fine Particulate Matter," ASME Power Test Code 28.